



**NAVAL
POSTGRADUATE
SCHOOL**

MONTEREY, CALIFORNIA

THESIS

**WASTE HEAT RECOVERY FROM A GAS TURBINE ENGINE
USING A HEAT EXCHANGER AND ASSOCIATED
CENTRIFUGAL COMPRESSOR VOLUTE DESIGN AND
SIMULATION**

by

Michael Kaim

June 2019

Thesis Advisor:

Co-Advisor:

Garth V. Hobson

Douglas L. Seivwright

Approved for public release. Distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 2019	3. REPORT TYPE AND DATES COVERED Master's thesis	
4. TITLE AND SUBTITLE WASTE HEAT RECOVERY FROM A GAS TURBINE ENGINE USING A HEAT EXCHANGER AND ASSOCIATED CENTRIFUGAL COMPRESSOR VOLUTE DESIGN AND SIMULATION			5. FUNDING NUMBERS	
6. AUTHOR(S) Michael Kaim				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			12b. DISTRIBUTION CODE A	
13. ABSTRACT (maximum 200 words) <p>The U.S. Department of Defense has implemented an initiative to become more energy efficient across all services. The Naval Postgraduate School supported development towards this goal by studying the possibility of energy generation using waste heat recovery within shipboard gas turbine engine exhaust. This research included the development of a heat exchanger ultimately to use compressed CO₂ as the working fluid to run a Brayton cycle. In support of this research, this thesis continued previous research regarding the Rolls Royce M250 helicopter engine and the heat exchanger previously designed. The heat exchanger was modified and the coils replaced using lessons learned from the previous iteration, and a second heat exchanger was built to match the first. The heat exchangers were installed on the engine's dual exhaust in order to gather measurements to determine how they would affect engine performance. The heat exchangers were tested using nitrogen to determine effectiveness. Additionally, a centrifugal compressor volute was designed utilizing a commercial impeller. An ANSYS CFD model was developed and tested to create a map of the compressor's performance utilizing air. The compressor was then manufactured using 3D printing technology and run using an independent electric motor so that the compressor and turbine can be run uncoupled at different speeds. This thesis was critical in the continuing development of a shipboard waste heat recovery system.</p>				
14. SUBJECT TERMS energy, waste heat recovery, gas turbine engine			15. NUMBER OF PAGES 97	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU	

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release. Distribution is unlimited.

WASTE HEAT RECOVERY FROM A GAS TURBINE ENGINE USING A HEAT EXCHANGER AND ASSOCIATED CENTRIFUGAL COMPRESSOR VOLUTE DESIGN AND SIMULATION

Michael Kaim
Lieutenant, United States Navy
BS, Virginia Military Institute, 2015

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

**NAVAL POSTGRADUATE SCHOOL
June 2019**

Approved by: Garth V. Hobson
Advisor

Douglas L. Seivwright
Co-Advisor

Garth V. Hobson
Chair, Department of Mechanical and Aerospace Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The U.S. Department of Defense has implemented an initiative to become more energy efficient across all services. The Naval Postgraduate School supported development towards this goal by studying the possibility of energy generation using waste heat recovery within shipboard gas turbine engine exhaust. This research included the development of a heat exchanger ultimately to use compressed CO₂ as the working fluid to run a Brayton cycle. In support of this research, this thesis continued previous research regarding the Rolls Royce M250 helicopter engine and the heat exchanger previously designed. The heat exchanger was modified and the coils replaced using lessons learned from the previous iteration, and a second heat exchanger was built to match the first. The heat exchangers were installed on the engine's dual exhaust in order to gather measurements to determine how they would affect engine performance. The heat exchangers were tested using nitrogen to determine effectiveness. Additionally, a centrifugal compressor volute was designed utilizing a commercial impeller. An ANSYS CFD model was developed and tested to create a map of the compressor's performance utilizing air. The compressor was then manufactured using 3D printing technology and run using an independent electric motor so that the compressor and turbine can be run uncoupled at different speeds. This thesis was critical in the continuing development of a shipboard waste heat recovery system.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I.	BACKGROUND	1
A.	ENERGY NEEDS OF THE U.S. NAVY	1
B.	WASTE HEAT RECOVERY ON U.S. NAVY SHIPS.....	1
C.	PRECEDING THESIS WORK.....	2
1.	“Waste Heat Recovery Carbon Dioxide Heat Exchanger for Gas Turbine Engines”: Polsinelli	2
2.	“Waste Heat Recovery System for a Gas Turbine Engine and Carbon Dioxide Compression Simulation”: Buck.....	3
D.	GOALS AND OBJECTIVES.....	3
II.	HEAT EXCHANGER MODIFICATION.....	5
A.	PREVIOUS THESIS WORK	5
B.	DESIGN MODIFICATIONS.....	7
C.	SECOND HEAT EXCHANGER.....	8
D.	RESULTS	9
1.	Limitations of the Manufacturing Process	9
2.	Final Product.....	9
III.	DATA ACQUISITION SYSTEM	11
A.	PREVIOUS WORK.....	11
B.	MATLAB CODING.....	11
1.	Temperature Measurements.....	11
2.	Pressure Measurements.....	12
3.	Mass Flow Measurements	12
4.	MATLAB Script Layout	12
5.	Local Functions	13
IV.	ENGINE AND HEAT EXCHANGER TESTING.....	15
A.	INSTRUMENTATION	15
B.	ENGINE TESTING	18
C.	HEAT EXCHANGER TESTING	21
V.	COMPRESSOR VOLUTE DESIGN.....	23
A.	BACKGROUND	23
B.	INITIAL VOLUTE DESIGN	23
C.	ANSYS CFX MODELING.....	27
1.	Design.....	27

2.	Mesh Setup	28
3.	Setup Block	29
4.	Solution Block.....	30
5.	Results	32
D.	ELECTRIC MOTOR ASSEMBLY	34
VI.	CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK	37
A.	CONCLUSIONS	37
B.	FUTURE WORK.....	37
	APPENDIX A. MATLAB DATA ACQUISITION SCRIPT	39
A.	CODE DESCRIPTION	39
B.	INITIALIZE.....	39
C.	USER INPUTS	40
D.	SYSTEM SETUP	40
E.	DATA GATHERING	43
F.	OUTPUT DATA.....	44
G.	FUNCTIONS.....	45
H.	PRESSURE BRICK INITIALIZATION CODE.....	50
I.	NATIONAL INSTRUMENTS LISTENER FUNCTION	51
	APPENDIX B. INSTRUMENTATION PORTS.....	53
A.	PRESSURE BRICK INSTRUMENTATION	53
B.	THERMOCOUPLE INSTRUMENTATION	54
	APPENDIX C. RAW MATLAB DATA	55
A.	20190130: STANDARD CONFIGURATION	56
B.	20190510: HEAT EXCHANGER CONFIGURATION	64
C.	20190531: HEAT EXCHANGER CONFIGURATION WITH COLD SIDE MEASUREMENTS	72
D.	20190605: HEAT EXCHANGER CONFIGURATION WITH COLD SIDE MEASUREMENTS	76
	LIST OF REFERENCES	81
	INITIAL DISTRIBUTION LIST	83

LIST OF FIGURES

Figure 1.	Illustration of Project End State.....	2
Figure 2.	Previous Heat Exchanger Design.....	6
Figure 3.	Modified Heat Exchanger.....	7
Figure 4.	Heat Exchangers Installed on Engine Exhaust.....	8
Figure 5.	Engine Diagram with Instrumentation. Adapted from [6].....	15
Figure 6.	Dual Heat Exchanger Configuration.....	16
Figure 7.	Heat Exchanger Cold Side Inlet Instrumentation.....	17
Figure 8.	Heat Exchanger Cold Side Outlet Instrumentation.....	18
Figure 9.	Power and BSFC vs. ND Speed.....	20
Figure 10.	Tongue Designed Using Circular Fillet.....	24
Figure 11.	Volute Sketches Used for Solid Model.....	25
Figure 12.	Final Volute Render with Impeller.....	25
Figure 13.	Half-Scale 3D Print of Volute with Impeller.....	26
Figure 14.	Final 3D Printed Volutes (Right) and Half-Scale Volute (Left).....	26
Figure 15.	Volute Negative Image for CFD.....	27
Figure 16.	Impeller Inflation and Edge Sizing.....	28
Figure 17.	Momentum and Mass RMS Residuals.....	31
Figure 18.	Logarithmic Plot Monitor of Mass Flow Rate Value.....	32
Figure 19.	Total Pressure Ratio vs. Mass Flow Rate.....	33
Figure 20.	Total to Total Isentropic Efficiency vs. Mass Flow Rate.....	33
Figure 21.	Scorpion Motor.....	34
Figure 22.	Cobra Controller.....	34
Figure 23.	Assembly Model of Volute, Impeller, and Motor Shaft.....	35
Figure 24.	Motor Shaft Sketch and Model.....	36

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

Table 1.	Engine Testing Speed Configurations	18
Table 2.	Engine Power Change.....	19
Table 3.	Engine BSFC Change	19
Table 4.	Engine Change in Backpressure at Power Turbine Exit.....	20
Table 5.	Heat Exchanger Coil Effectiveness vs. Engine ND Speed	21
Table 6.	Heat Exchanger Coil Temperature Change vs. Engine ND Speed.....	22
Table 7.	CFD Domain Settings	29

THIS PAGE INTENTIONALLY LEFT BLANK

I. BACKGROUND

A. ENERGY NEEDS OF THE U.S. NAVY

The Department of Defense (DoD) is the nation's largest consumer of energy. In FY2016 the DoD consumed 86 million barrels of fuel [1]. Of that number, the U.S. Navy consumed 28.5 million barrels of fuel, or 33.26% of the total. From a 2010 memorandum of understanding between the DoD and the Department of Energy, "Energy efficiency could serve as a force multiplier, increasing the range and endurance of forces in the field while reducing the number of combat forces diverted to protect energy supply lines, as well as reducing long-term energy costs" [2]. Because of this, the DoD has launched several energy initiatives to improve energy efficiency and reduce the consumption of fossil fuels. In support of these initiatives, the Department of the Navy aspires to have 50% of all energy for installations produced by renewable methods by 2020 [3]. It is clear the Navy has a vested interest in reducing fuel consumption without reducing fleet capabilities.

B. WASTE HEAT RECOVERY ON U.S. NAVY SHIPS

Improving energy efficiency on ships can be a daunting task. The common renewables of solar and wind are not feasible for Navy ships, both because of the lack of deck space available for solar panels and the high profile of wind turbines. One method that could potentially be retrofit onto any platform is waste heat recovery. The Ticonderoga class of U.S. cruisers had such a system installed on all 27 ships of the class. The systems operated on the Rankine Cycle, using boilers to generate steam to be used for ship services such as heating, laundry and galley equipment. The systems were plagued by high operational costs due to the steam's corrosive nature as well as a reduction in stability caused by the additional weight high above the ship's center of gravity. As a result, these systems were removed during the "all-electric modification," replacing the waste heat boilers and associated equipment with electrical appliances [4]. Future systems would have to be non-corrosive and lightweight.

This project seeks to design a waste heat recovery system based on the Brayton Cycle utilizing carbon dioxide as the working fluid instead of wet steam. A diagram of this

end state is shown in Figure 1. Additionally, this project seeks to decouple the compressor and turbine by connecting them to electric motors, allowing them to spin independently at different speeds specific to their on-design points. This serves a dual purpose of also generating recovered energy locally at the heat exchanger in the form of electricity, removing the need for intricate piping throughout the ship.

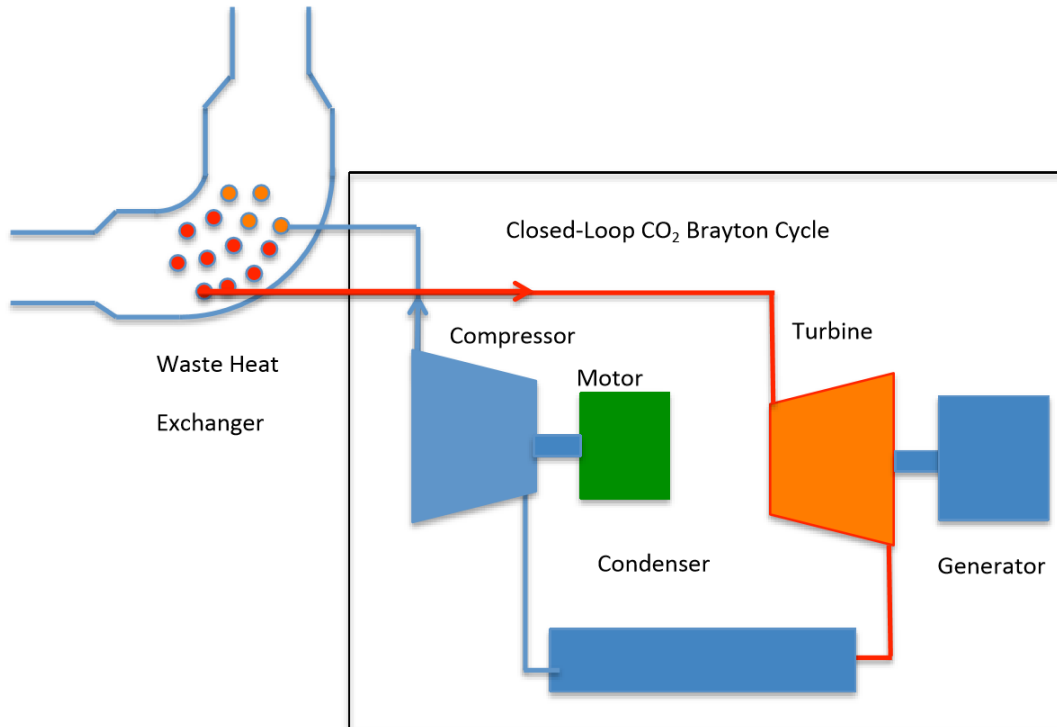


Figure 1. Illustration of Project End State

C. PRECEDING THESIS WORK

1. “Waste Heat Recovery Carbon Dioxide Heat Exchanger for Gas Turbine Engines”: Polsinelli

Polsinelli [5] created a cylindrical heat exchanger design that consisted of four coils installed concentrically within. This design allowed for flow in either series or parallel. Polsinelli also analyzed his heat exchanger design utilizing computational fluid dynamics (CFD) to determine both the effectiveness of the heat exchanger and any detrimental influence on the engine. His design maximized the recovery of heat while minimizing the

impact on performance. His work also included the exhaust ducting and bell mouth for the Roll Royce M250 T63-A-720 gas turbine engine used for testing components for this thesis.

2. “Waste Heat Recovery System for a Gas Turbine Engine and Carbon Dioxide Compression Simulation”: Buck

Buck [6] took Polsinelli’s heat exchanger design and manufactured the first prototype. This prototype was mounted on one of the two exhaust ducts for the T63 engine and engine performance tests were run where measurements were then compared to the baseline. Buck also initiated the design for the Brayton Cycle’s centrifugal compressor by making a CFD model of the impeller housing using a commercial turbocharger compressor impeller.

D. GOALS AND OBJECTIVES

Using lessons learned from the previous iteration of the heat exchanger, the manufacturing and design process was modified to improve consistency across each design iteration and reduce the damage to the coils sustained through the bending process. A second heat exchanger was built to match the updated design so that both exhaust ducts for the T63 engine would experience a similar back pressure and reduction in flow. The new heat exchangers would both be mounted on the engine so that the performance degradation could be adequately measured across the engine’s operating envelope. The performance of the heat exchanger was also determined. A gas distribution system and associated instrumentation were added so that an effectiveness of the heat exchanger was calculated. Nitrogen gas was initially tested because of its ready availability and carbon dioxide would follow.

To accomplish the above tasks, the data acquisition system was modified to increase measurement accuracy and sampling rate as well as including a standard deviation routine to provide the user an indication of data outside the expected norms. The data would need to be output into a file format that could be used in any post processing program. Finally, the program should output the raw data to provide transparency for the processed data such that it could be verified independently.

Separately, the centrifugal compressor design was advanced by designing the diffuser and volute, resulting in a completed prototype for testing. The compressor would also have to be assembled and the necessary components selected and procured or designed as necessary. Finally, a CFD model was produced for the volute to predict performance so the design could be adapted and improved with tangible data.

II. HEAT EXCHANGER MODIFICATION

A. PREVIOUS THESIS WORK

The previous heat exchanger prototype designed by Polsinelli [5] and manufactured by Buck [6] consisted of 4 stainless steel tubes each coiled 9 times at a diameter of 15.24, 20.32, 25.4, and 30.48 cm (6, 8, 10, and 12 inches). Each tube has an inner diameter of 0.762 cm (0.3 in) and was coiled using a Baileigh Ring Roller R-M5. Each tube was combined concentrically inside of a clamshell assembly consisting of two halves that were approximately 60.96 cm (2 feet) tall. On one half of the clamshell there were 8 openings, 4 on the top right and 4 on the bottom left as a means to allow the coil ends to pass through the shell. For the counter flow parallel configuration, the top holes would be the inlet and the bottom holes would be the outlet. Each opening would have a brass bushing to hold the coils in place; each bushing was held in place by a spring pin. These holes were built within a plate with the same radius of curvature as the clamshell which was secured by threaded screws to prevent hardware from coming loose due to engine vibration and falling into the engine. The top of the heat exchanger was topped with a conical nozzle.

Inside the heat exchanger, the coils were held in place using stainless steel braces that consisted of two plates with holes that would clamp around the tubing. These were secured together with rivets and screwed to the clamshell. Each brace was installed approximately 60 degrees apart and placed equally from top to bottom.

Due to manufacturing difficulties as shown in Figure 2, several changes were identified to improve on Polsinelli's design. The first involved the orientation of the coil ends to the inlet and exit holes on the clamshell. The initially chosen diameters of the coils required excessive bends to be incorporated in order to align the tube ends with the inlet and outlet holes, often resulting in kinking as shown in Figure 2. The spring pins used in the initial design to hold the coil bushings in place were found to fall out during engine runs resulting in one instance of a bushing being blown off the coil tube end and across the engine test cell. Lastly, the screws used for assembling the two clamshell halves of the heat

exchanger were found to seize and oxidize due to the high temperatures. This made it difficult to disassemble the units for configuration changes and design improvements.



Figure 2. Previous Heat Exchanger Design

B. DESIGN MODIFICATIONS

After observing the amount of bending the tubing required to be fit through the holes in the clamshell, the design was modified to use 10.16, 15.24, 20.32, and 25.4 cm (4, 6, 8, and 10 inch) coils. Each was coiled 9 times as before and stretched to approximately 60.96 cm (2 feet). This modification allowed the tubing to enter and exit the clamshell in a more tangential direction relative to each coil's circumference, thus eliminating the "alignment" bending required and the associated obstructions to the flow it caused as seen in Figure 3.

After the coils were modified, the internal clamps had to be modified as well to accommodate the smaller diameters. To prevent the tubing and bushings from coming loose due to vibrations, the spring pins were replaced with set screws. To prevent seizing, all screws were replaced with high temperature screws and installed using anti-seize compound.



Figure 3. Modified Heat Exchanger

C. SECOND HEAT EXCHANGER

At the start of this thesis, one of the design goals was to modify the exhaust nozzle outlet diameter to reduce the backpressure on the engine while maximizing the effectiveness of the heat exchanger. However, with two exhaust ducts from the power turbine, any modification to one exhaust would be accompanied by a change in the flow in the other. Therefore, a second heat exchanger was needed to ensure the exhaust flow was predictable to allow for future design modifications.

While producing the modified heat exchanger, each component was duplicated using the same construction methods. This was intended to keep the designs as consistent as possible. Therefore, each coil was produced in pairs using the same coil settings. Figure 4 shows the completed heat exchangers installed on the engine exhaust.



Figure 4. Heat Exchangers Installed on Engine Exhaust

D. RESULTS

1. Limitations of the Manufacturing Process

The Baileigh Ring Roller R-M5 was a manual tube coiler machine that has two screws for setting the coil diameter. There were no fixed intervals or settings, so they were made by trial and error. Any misalignment in the feeding process would result in a change in coil diameter. The coils also had to be stretched manually, and the tighter the coil diameter the more rigid it became. This resulted in coils that were of varying heights and required further stretching and compression to keep the spacing consistent.

The clamshell components were welded together and could not be modified without replacing the component entirely. This led to misalignment in the clamshell bolt holes and caused difficulty in assembling the final product. The inlet and outlet holes for the tubing were still assembled at a greater angle than the original design required due to limitations in the manufacturing process. All these aspects provided for possible design modifications for future work.

2. Final Product

In the end there were two completed heat exchangers that were similar enough for experimentation. They were fitted with exhaust nozzles of the same diameter as well as outfitting of instrumentation ports placed before and after the coils. The improvements resulted in a smoother flow path of the tubing, reducing those losses that would result from the excessive bends.

THIS PAGE INTENTIONALLY LEFT BLANK

III. DATA ACQUISITION SYSTEM

A. PREVIOUS WORK

Belna [7] did thesis work in support of the NPS Transonic Compressor test rig. His goal was to create a data acquisition (DAQ) system using MATLAB to take temperature, pressure, and mass flow measurements for the test rig. With some modifications his code was valuable for creating a DAQ system for the Marine Propulsion Laboratory's T63 Gas Turbine Engine. Belna utilized National Instruments (NI) hardware for temperature and mass flow measurements as well as Scanivalve Digital Sensor Arrays (DSAs) for pressure measurements. His program was used as the basis for the DAQ system used for this engine project. The MATLAB code used for this thesis is included in Appendix A

B. MATLAB CODING

1. Temperature Measurements

Temperature measurements were collected using K-Type thermocouples connected to an NI-9214 Module. Each module accommodated 15 temperatures since the module had 16 channels but the 0th channel could not be used in MATLAB. The T63 required 11 thermocouple readings for various engine performance parameters and the heat exchanger required 8. Two NI-9214 modules were used, the first one for the engine measurements and the second for the heat exchanger's cold side. The NI hardware was read into MATLAB using the Data Acquisition Toolbox.

Within MATLAB, the temperature code created a data acquisition session using the `daq.createSession('NI')` command. Thermocouples were added to the session using the `addAnalogInputChannel` command, and they were designated as K-Type thermocouples with units of Kelvin. A listener was created with the `addlistener` command to monitor these channels in real time. A separate function was created to recall the data and output it to a global variable. When the code was run, the `startBackground` command was used to initialize the DAQ session in the background.

2. Pressure Measurements

Pressure measurements were taken using the Scanivalve DSA 3217 pressure bricks. Three pressure bricks were used; 2.5, 17.2, and 689.5 kPa (10 inH₂O, 2.5 PSID, and 100 PSID) to ensure adequate resolution was available. This hardware interfaces with MATLAB's instrumentation control toolbox. The T63 engine required 14 pressure measurements: 2 for the bell mouth inlet, 2 for the compressor and 10 on the exhaust ducts. An additional two ports were utilized for the cold side of the heat exchanger, one at the inlet manifold and one at the exit manifold.

The pressure bricks operated through objects that were created and assigned to the IP address of each brick. Standard settings were designated using the `fprintf` command for each brick. The instantaneous pressures were read using the `fscanf` command and output into vectors. These vectors were combined into a single matrix for processing and output.

3. Mass Flow Measurements

Mass Flow readings for the heat exchangers were taken using ValuMass Thermal Mass 400 Series Flowmeters and the raw voltages were read directly into MATLAB with an NI 9201 module and the data was output alongside temperatures. Calibration data was obtained by comparing the readout to the output voltages.

4. MATLAB Script Layout

The general plan for the code was initially to take the temperature and pressure measurements at the same time within the same for-loop. This utilized the `fscanf` command for the pressure bricks and the `inputSingleScan` command for the temperature modules. The `inputSingleScan` command ended up taking a significant amount of time to execute which increased linearly with each additional channel utilized.

In order to speed up execution, a listener function was introduced to allow the NI hardware to gather data in the background. Upon testing, it became clear that without a pause of at least 0.1 seconds, there would be no NI data output to the workspace for processing. By setting the DAQ scan rate to 1 scan per second, the function could be easily synchronized to the pressure for-loop. This was done by calculating the time it took to

gather the pressure readings using the tic/toc commands and forcing the loop to pause for the remainder of the second.

An additional time-saving measure that was implemented was to preserve the listener and DAQ session variables between runs using the “clearvars” command which allowed specification of variables to keep. The code was modified to check to see if these variables existed before running the lines of code that created them. As a result, the first run after clearing all variables would take approximately 22 seconds just to build and execute the DAQ session variable, but all subsequent runs would skip this step entirely. There was no need for these variables to be rebuilt with each run of the code. Each time the session was stopped with the “stop” command, it could be restarted from the beginning with the “startBackground” command.

5. Local Functions

The script took advantage of several local functions defined at the end of the script. The first of these functions was run at the beginning of each execution to define date and time stamps for the run. These were later used to provide unique names for each data point to assist with data processing. The date stamp was also used to define the data output files which were created in the second local function.

The second local function took the date and time stamps from the first function and generated unique data output files for each day. Each time the function was called, it checked to see if the file containing that day’s date stamp exists and if it didn’t, the function created it. This function also defined the first lines of each file which correspond to channels and ports for the output data. The files were tab-delimited, so they could be read into any program that accepts such files, such as Excel or MATLAB depending on user preference.

The final local function took the raw data from the main script and generated the output files for each type of data. There were 6 output files which were clearly defined by the second local function by name. The NI data was separated into temperature and voltage data, and each of these were accompanied by their relative standard deviations (4 files). The pressure data was consolidated into a single file and was accompanied by a relative

standard deviation file as well (2 files). The final 2 files are the raw data output files, one for the NI hardware and one for the Scanivalve hardware. These raw files ensure transparency so that no calculations are done in the background that could not be verified independently.

IV. ENGINE AND HEAT EXCHANGER TESTING

A. INSTRUMENTATION

The T63 engine, as shown in Figure 5, was tested under two configurations to evaluate the effect of heat exchangers on performance; a standard configuration with two unmodified exhaust ducts and two ducts incorporating the heat exchangers on each. For both configurations, the engine had thermocouples for measuring temperatures at the compressor inlet, compressor outlet, gas generator turbine exit (T5), and the left and right exhaust (power turbine exit). There were also pressure taps located at the compressor inlet for total and static, the compressor outlet static, and the left and right exhaust static pressures.

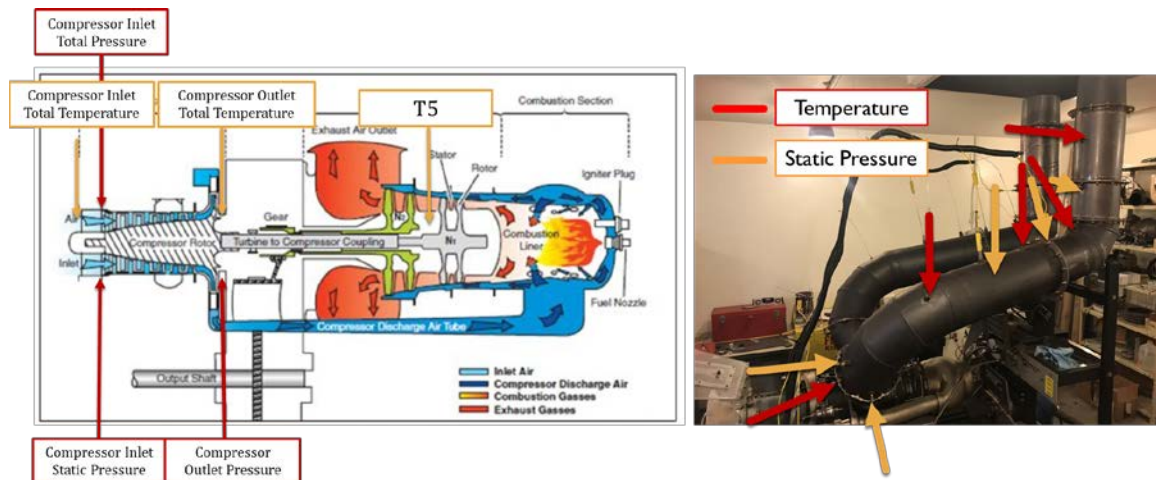


Figure 5. Engine Diagram with Instrumentation. Adapted from [6].

For the standard configuration, there were 4 pressure taps along the length of the exhaust as well as 4 temperature probes. This was to obtain an adequate temperature and pressure profile for the exhaust ducts for comparison to the heat exchanger configuration to determine if significant backpressure and temperature profiles were present.

For the double heat exchanger configuration, there were insufficient instrumentation ports to include both thermocouples and pressure measurements as was the case for the unmodified duct configuration. Additionally, temperature measurements before and after the heat exchanger were required so that an effectiveness could be calculated. This meant that in order to obtain representative temperature and pressure data, one heat exchanger needed to be fit with thermocouples and the other with pressure taps. For this experiment, the right heat exchanger had thermocouples and the left had pressure taps. The right heat exchanger would be used to test the heat exchanger effectiveness by running Nitrogen through it, while the left heat exchanger would be used to determine the pressure drop. For analysis purposes, the pressure drop through the heat exchanger was assumed to be the same in each heat exchanger. The heat exchangers with their associated instrumentation are shown below in Figure 6.

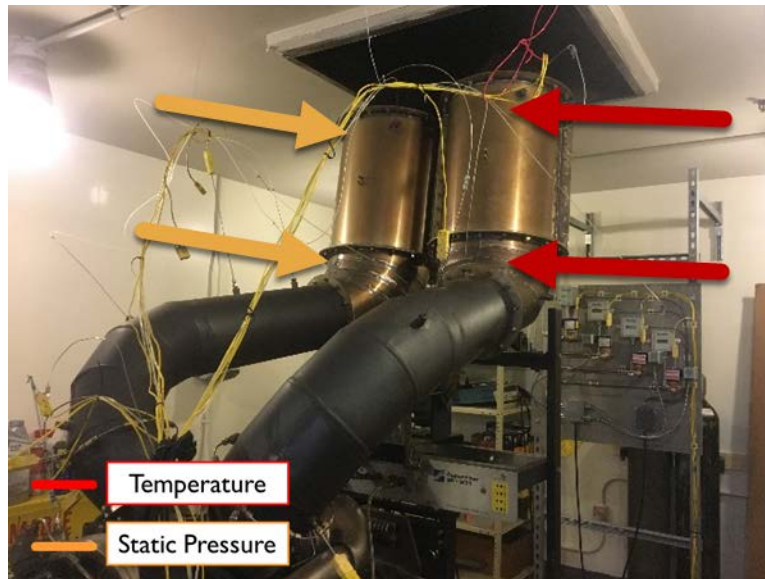


Figure 6. Dual Heat Exchanger Configuration

The heat exchanger cold side had its own instrumentation measurement system. Compressed nitrogen was fed into a manifold where the flow was divided in four lines. Static pressure was measured at the manifold. Each line had its own mass flow meter and thermocouple. The flow in each line could be individually controlled by solenoid valves. This setup is shown in Figure 7. At the exit of the heat exchanger there were four more thermocouples, and each line was fed back into another manifold where another pressure measurement was taken. The nitrogen was then throttled through a valve and dumped to the ambient surroundings above the heat exchanger exhausts. This setup is shown in Figure 8. In all, the cold side added eight additional thermocouple channels, 2 pressure taps, and 4 voltage readings for mass flow measurements to the instrumentation code.

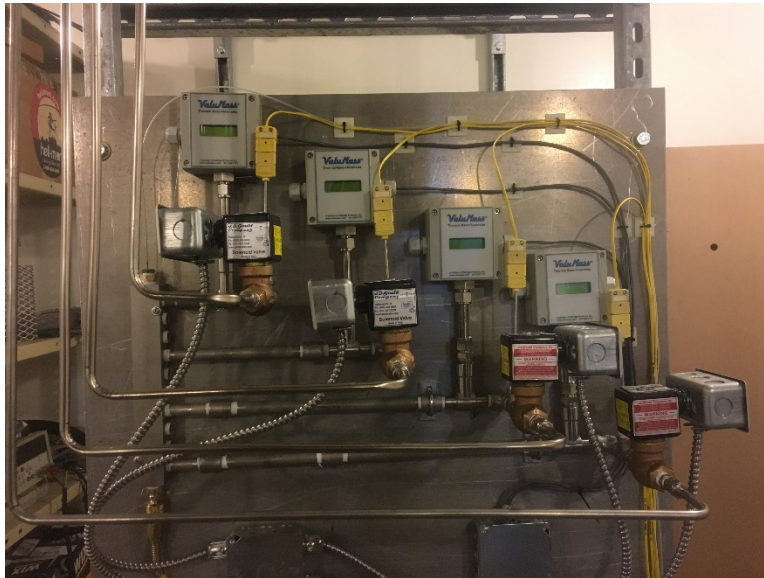


Figure 7. Heat Exchanger Cold Side Inlet Instrumentation

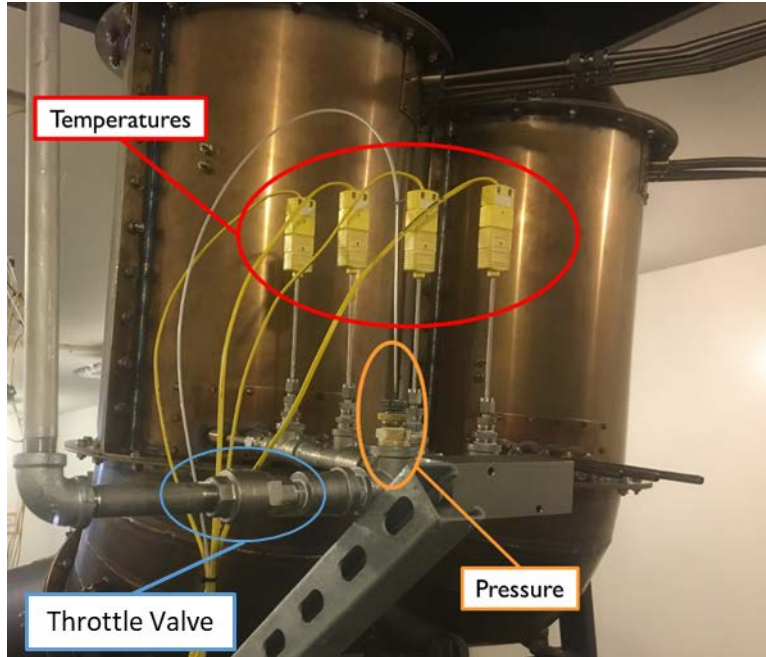


Figure 8. Heat Exchanger Cold Side Outlet Instrumentation

B. ENGINE TESTING

Engine testing was based on three pre-defined gas generator speed lines as shown in Table 1. For each speed line, 5 operating points were chosen. N1 corresponds to the gas generator compressor speed, N2 corresponds to the power turbine speed, and ND corresponds to the dynamometer speed which was used to apply a load to the engine.

Table 1. Engine Testing Speed Configurations

N1 (RPM)	ND (RPM)	ND (RPM)	ND (RPM)	ND (RPM)	ND (RPM)
40890 (80%)	3600	4200	4800	5400	6000
46000 (90%)	3600	4200	4800	5400	6000
51000 (100%)	3600	4200	4800	5400	6000

The data is reported in Table 2 below for the case with no heat exchangers compared to the case with both heat exchangers installed. On the 100% speed line (51,000 RPM on N1) there was a maximum 10.8% reduction in power.

Table 2. Engine Power Change

ND (RPM)	Baseline (kW)	Heat Exchangers (kW)	Percent Change
3600	237.43	217.04	-8.59%
4200	252.87	229.15	-9.38%
4800	269.94	244.71	-9.35%
5400	281.20	250.91	-10.77%
6000	290.38	259.69	-10.57%

The heat exchangers also influenced the Brake Specific Fuel Consumption (BSFC), resulting in a maximum increase of 7.13%. These values are summarized in Table 3 and plotted in Figure 9 below.

Table 3. Engine BSFC Change

ND (RPM)	Baseline (kg/kw-hr)	Heat Exchangers (kg/kw-hr)	Percent Change
3600	0.418	0.439	5.01%
4200	0.384	0.404	5.19%
4800	0.364	0.388	6.72%
5400	0.352	0.378	7.25%
6000	0.345	0.370	7.13%

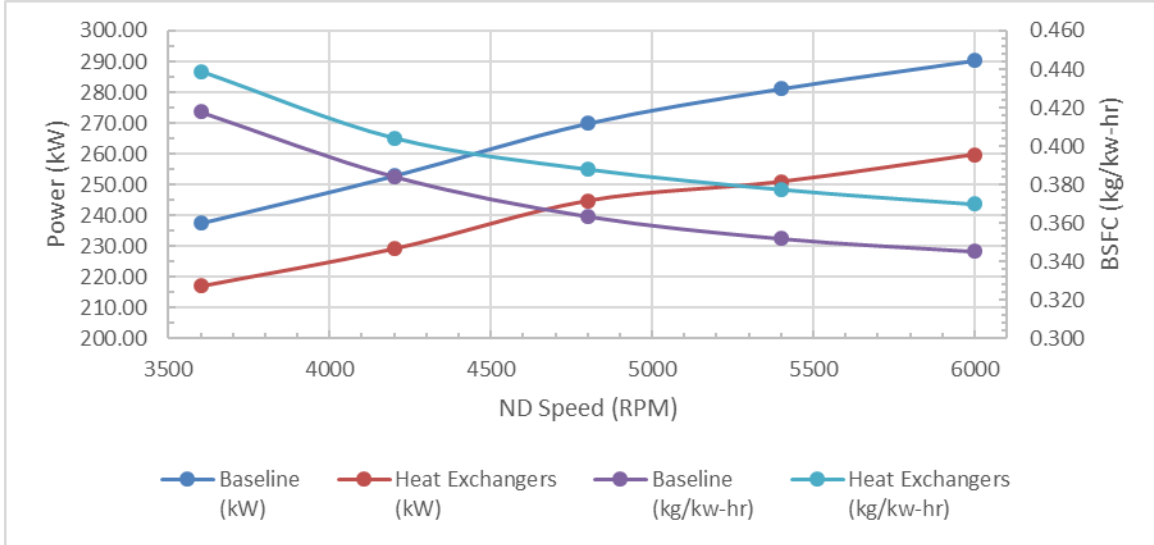


Figure 9. Power and BSFC vs. ND Speed

The effect of the heat exchangers on the backpressure at the turbine exit was also measured to account for any performance reduction. The backpressure change was consistent across each data point, with a maximum 2.79 kPa increase in absolute pressure.

Table 4. Engine Change in Backpressure at Power Turbine Exit

ND (RPM)	Baseline (kPa)	Heat Exchangers (kPa)	ΔP (kPa)
3600	101.08	103.63	2.56
4200	101.02	103.58	2.56
4800	101.17	103.87	2.69
5400	101.51	104.31	2.79
6000	102.23	104.62	2.40

C. HEAT EXCHANGER TESTING

The heat exchanger was tested by running the engine at the 100% speed line and running compressed nitrogen through the coils. During the run it was discovered that there were several leaks in the heat exchanger clamshell that dumped hot exhaust gases over the instrumentation. Thermocouples had to be replaced several times before identifying the issue. As a result, the measured outlet temperatures for the heat exchanger may have been compromised as a result of hot exhaust gasses on the thermocouples. The final engine run resulted in the four outlet thermocouples melting as well as the pressure tap. The setup of the manifold and all instrumentation for the cold side outlet will need to be modified for future experimentation. However, the data is summarized below in Tables 5. Effectiveness was calculated utilizing Equation 1 which is the common form of the effectiveness equation used in many heat transfer texts. T_{Co} , T_{Ci} , and T_{Hi} are the temperatures at the cold side outlet, inlet, and hot side inlet, respectively. C_C and C_{min} are the heat capacities for the cold side fluid and the minimum of the hot and cold side heat capacity, respectively. Table 6 shows the change in temperature of the nitrogen gas as it passed through the heat exchanger.

$$\varepsilon = \frac{C_C (T_{Co} - T_{Ci})}{C_{min} (T_{Hi} - T_{Ci})} \quad (1)$$

Table 5. Heat Exchanger Coil Effectiveness vs. Engine ND Speed

Size (cm)	3600 (RPM)	4200 (RPM)	4800 (RPM)	5400 (RPM)	6000 (RPM)
10.16	58.22%	36.24%	37.97%	38.47%	39.06%
15.24	29.84%	38.13%	39.28%	40.80%	39.91%
20.32	29.70%	40.88%	45.68%	44.63%	38.85%
25.4	38.58%	59.60%	63.22%	68.17%	71.77%

Table 6. Heat Exchanger Coil Temperature Change vs. Engine ND Speed

Size (cm)	3600 (RPM)	4200 (RPM)	4800 (RPM)	5400 (RPM)	6000 (RPM)
10.16	345.79	210.77	223.71	228.33	232.88
15.24	177.13	221.67	231.32	242.06	237.85
20.32	176.28	237.59	269.00	264.75	231.52
25.4	165.16	216.89	227.88	240.26	248.83

Temperatures are degrees Kelvin

V. COMPRESSOR VOLUTE DESIGN

A. BACKGROUND

For the overall goal of the CO₂ Brayton Cycle, a compressor needed to be designed. Centrifugal compressor volutes are typically designed from a manufacturability perspective. They are often cast which makes design changes difficult and costly. Using 3D printing technology, the volute could be made at minimal cost and allow flexibility for a quick turn around when improvements to the design are made.

Buck [6] designed an impeller housing around a commercial turbo charger compressor impeller. This thesis sought to design a volute into which that impeller housing would discharge.

B. INITIAL VOLUTE DESIGN

One study conducted by Xu and Muller [8] suggested that the tongue design was critical for performance. In that study they investigated several tongue geometries, each relating the radius of the tongue, r , to the height of the impeller exit, b (Figure 10). They tested 4 tongue designs and found that a sharp tongue provided the absolute peak efficiency, but a rounded tongue provided better off-design performance and better flow characteristics.

Because this compressor would be for a Brayton Cycle that has yet to be designed, a rounded tongue was selected for its better off design performance. This was to facilitate testing since the flow characteristics in the heat exchanger would need to be mapped to identify the best performance parameters. For simplicity, a 1 mm radius was selected. The impeller exit height was 4.8 mm for comparison, which resulted in an $r/b = 20.8\%$. Figure 10 shows the volute tongue as drawn and tested.

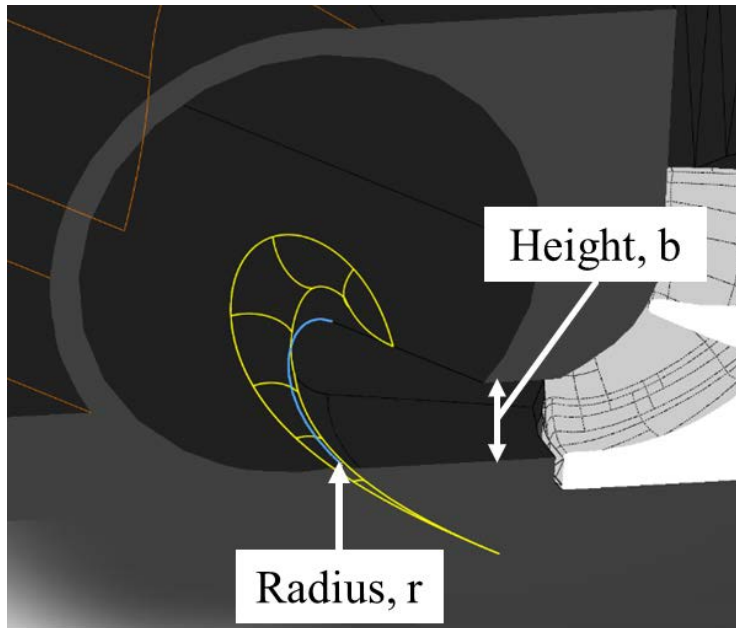


Figure 10. Tongue Designed Using Circular Fillet

The design was developed using SolidWorks. The initial impeller housing developed by Buck was used as the basis for the volute. In her design, the turbocharger compressor impeller was scanned into a SolidWorks model and the housing was built around it to ensure a good fit. For the volute, the external shape including the base flange was produced by creating a cross section and revolving it around the centerline. To form the internal volute, 8 circles of graduated diameters were drawn 45 degrees apart from each other, starting at 25.4 mm (1 in) and ending with the impeller exit height of 4.8 mm (0.189 in). The circles were tangent to the base plane and were kept equidistant from the center using a base circle. These circles were then used to create a lofted cut through the external shape to create the circular cross section. The sketches described are shown in Figure 11. A simple rectangular revolved cut was used for the vaneless diffuser. To finish the model, the outlet was extruded from the 25.4 mm (1 in) circle and was a constant diameter. The base circle was 37.4269 mm (1.4735 in) in diameter. A half scale model printed in two halves was printed to illustrate the interior design on an Ultimaker Go. The final model was printed at full scale with an Ultimaker 3 printer. The final render is shown in Figure 12. The half scale model is shown in Figure 13 and the final print is shown in Figure 14.

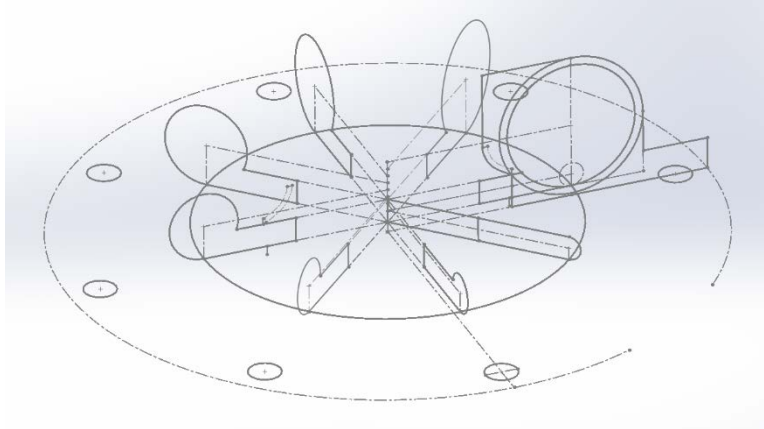


Figure 11. Volute Sketches Used for Solid Model

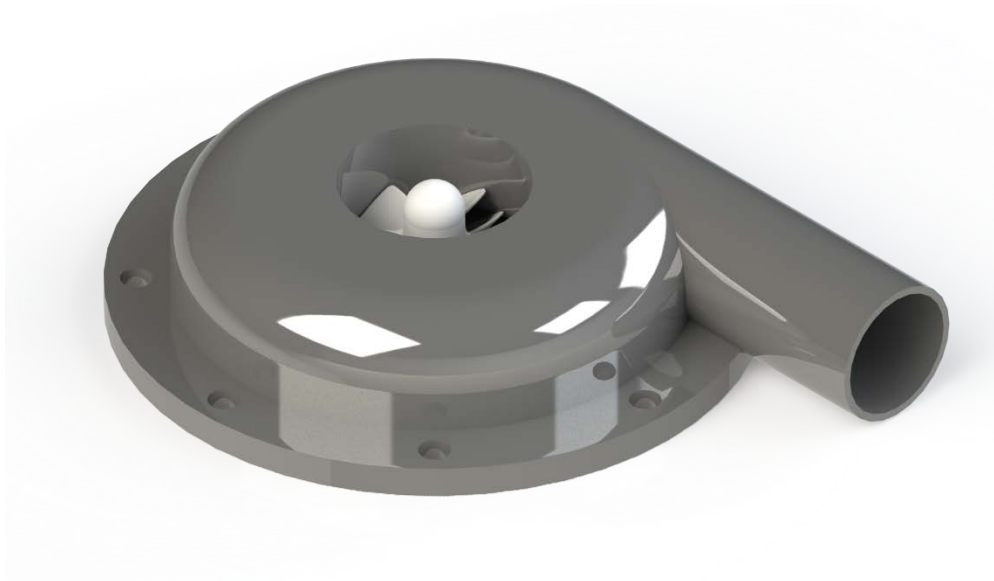


Figure 12. Final Volute Render with Impeller

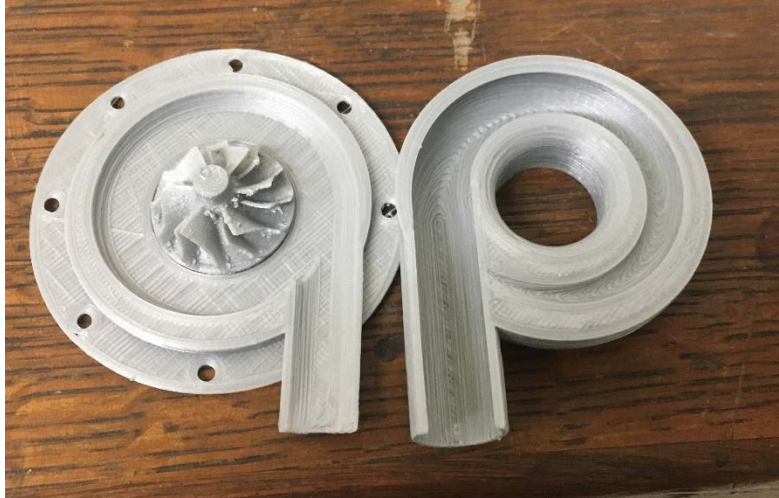


Figure 13. Half-Scale 3D Print of Volute with Impeller



Figure 14. Final 3D Printed Volutes (Right) and Half-Scale Volute (Left)

C. ANSYS CFX MODELING

1. Design

A model of the volute was developed for ANSYS CFX. A negative image of the volute was drawn by subtracting a solid model from the volute, leaving the internal structure. This negative image is shown in Figure 15. The model was split into two domains, one for the impeller and one for the volute. During setup, the impeller domain was set to rotate while the volute domain was stationary. The two domains were connected via an interface. The goal of the CFX model was to determine the pressure ratios that could be achieved as well as their efficiencies. Therefore, this analysis went from no backpressure through the peak efficiency point but did not include the stall point. The model would be run at 100,000 RPM as this was the design goal where the compressor volute would be tested.

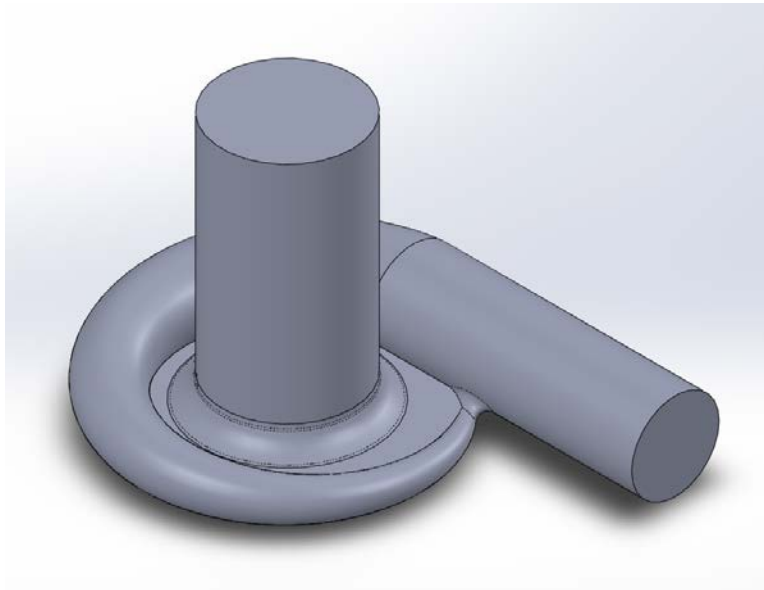


Figure 15. Volute Negative Image for CFD

2. Mesh Setup

The goal of the CFD analysis was to estimate design performance. As a result, the mesh used was relatively coarse to reduce the time it would take to gather data points. Even still, a typical solution would take upwards of 24 hours for a single data point, accounting for the adaptation of settings between runs to achieve the best convergence.

The mesh was made using mostly the default settings. In order to improve simulation accuracy while reducing the time for each solution, Face Sizing and Inflation settings were implemented on the impeller surface. For the Face Sizing, the curvature normal angle was set to 2 degrees and the local minimum size was set to 0.25 mm. For the Inflation, the number of layers was set to 4 with a growth rate of 1.2. The maximum thickness of the inflation was set to 1.0 mm. In order to reduce the overall size of the mesh, a global growth rate of 1.4 was chosen. This ensured the mesh close to the surfaces would be fine enough for a good solution, while reducing the mesh size towards the center of the flow. Figure 16 is an image of the inflation and edge sizing on the surface of the impeller.

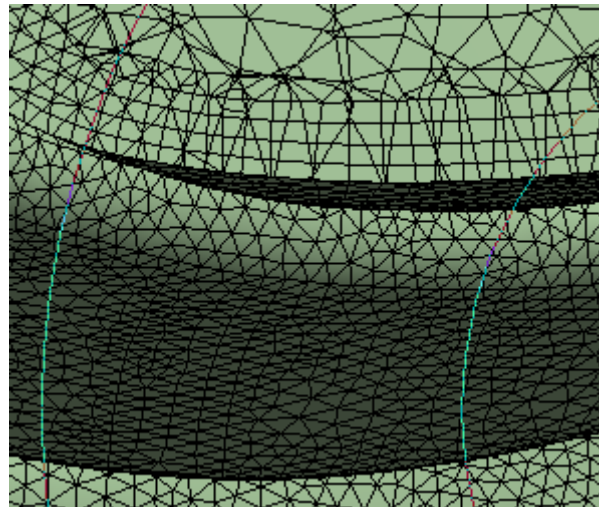


Figure 16. Impeller Inflation and Edge Sizing

3. Setup Block

The setup was split into two domains. For the impeller domain, which would be rotating, the angular velocity was defined using an expression called “RPM” that could be parameterized in the Workbench interface. The variable was made negative within workbench to ensure it would be the right direction no matter the user input. Air Ideal Gas was used as the working fluid. Heat Transfer was set to “Total Energy” and the Turbulence Model used was k-Epsilon. The volute domain used the same settings, except it was stationary. The settings are summarized in Table 7 below.

Table 7. CFD Domain Settings

	Impeller	Volute
Material	Air Ideal Gas	Air Ideal Gas
Reference Pressure	1 [atm]	1 [atm]
Buoyancy Model	Non Buoyant	Non Buoyant
Domain Motion	Rotating	Stationary
Angular Velocity	"-abs(RPM)"	N/A
Heat Transfer	Total Energy	Total Energy
Turbulence	k-Epsilon	k-Epsilon
Wall Function	Scalable	Scalable

For the solver, the settings were varied over the course of the project. The main parameter that was modified was the Fluid Timescale Control. The default Auto Timescale and Conservative Length Scale options were used, but the timescale factor was reduced to 0.75. Later, a fixed timescale was used and defined by an expression that tied the time step size to the angular velocity such that one timestep would cover 3 degrees of rotation. This setting resulted in the best convergence, but also took several days for a single data point. The Residual target was set to 1e-9 to allow the solver to run through the set iterations. All other solver settings were kept the same.

The process of obtaining data points was iterative. The first iteration involved parameterizing backpressure from 0.0 atm to 0.4 atm to obtain solver files. These solver files were then used to identify a mass flow rate and provide initial conditions for the next solution. Specifying the mass flow rate with a previously generated results file proved to be the best method for convergence. For the backpressure solution, the static pressure was specified at the inlet as 0 atm and the opening pressure was specified at the outlet by an expression for parameterization. For the mass flow solution, the mass flow rate was set at the inlet and the outlet was set to an opening with an opening pressure of 0 atm.

4. Solution Block

Within the solution block, the backpressure runs were set to start from initial conditions while the mass flow rate runs were initialized with a results file from the backpressure runs. The mass flow rate residuals were monitored, as well as the mass flow rate values at both the inlet and outlet. In order to ensure good convergence, a variable was specified for the standard deviation over 100 iterations and plotted in a separate monitor. When the standard deviation flattened out and was not getting any lower, the solution was considered converged. Using this method, standard deviations as low as 10^{-9} were achievable. An example residuals plot is included in Figure 17 along with the mass flow rate plot from the same solution in Figure 18. These plots came from specifying the backpressure followed by the mass flow rate.

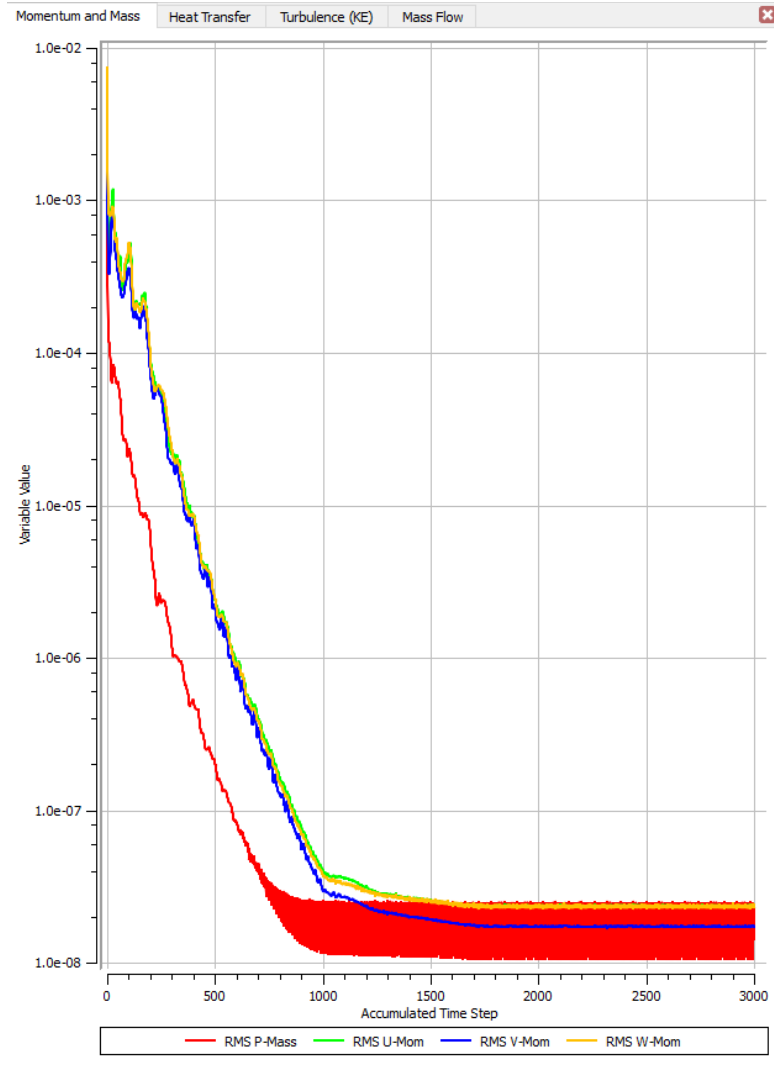


Figure 17. Momentum and Mass RMS Residuals

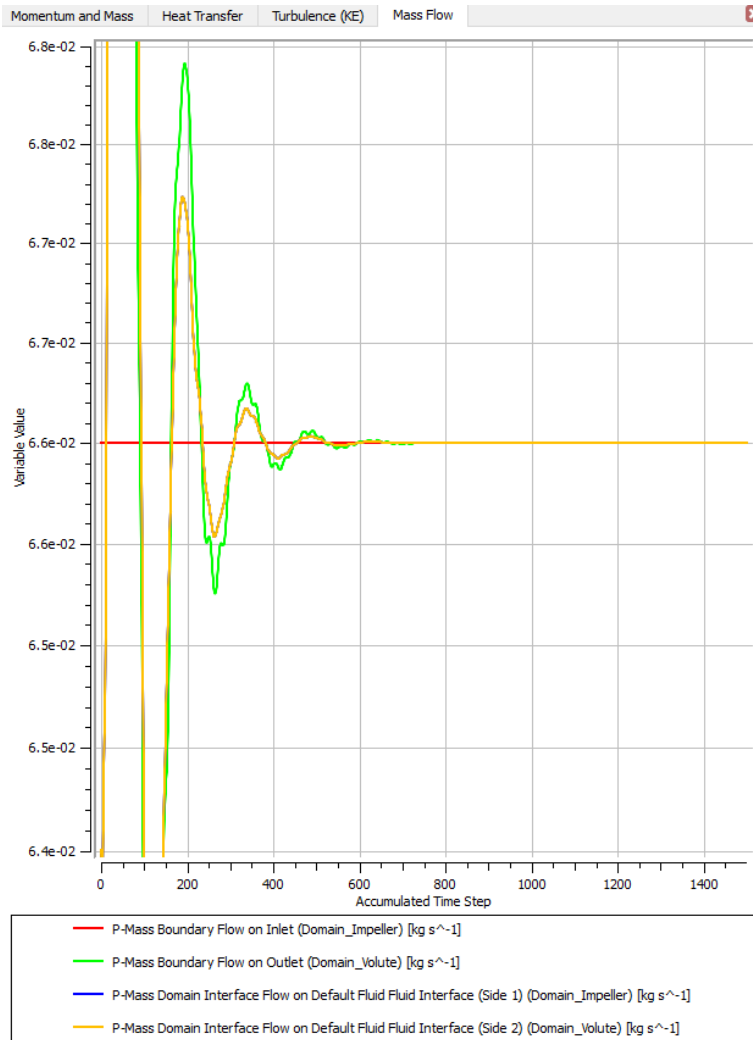


Figure 18. Logarithmic Plot Monitor of Mass Flow Rate Value

5. Results

The maximum efficiency achieved was 68.5% at a mass flow rate of 0.069 kg/s. This mass flow rate resulted in a total pressure ratio of 1.35 and this would require approximately 2.5 kW of power. The data is plotted in figures 19 and 20.

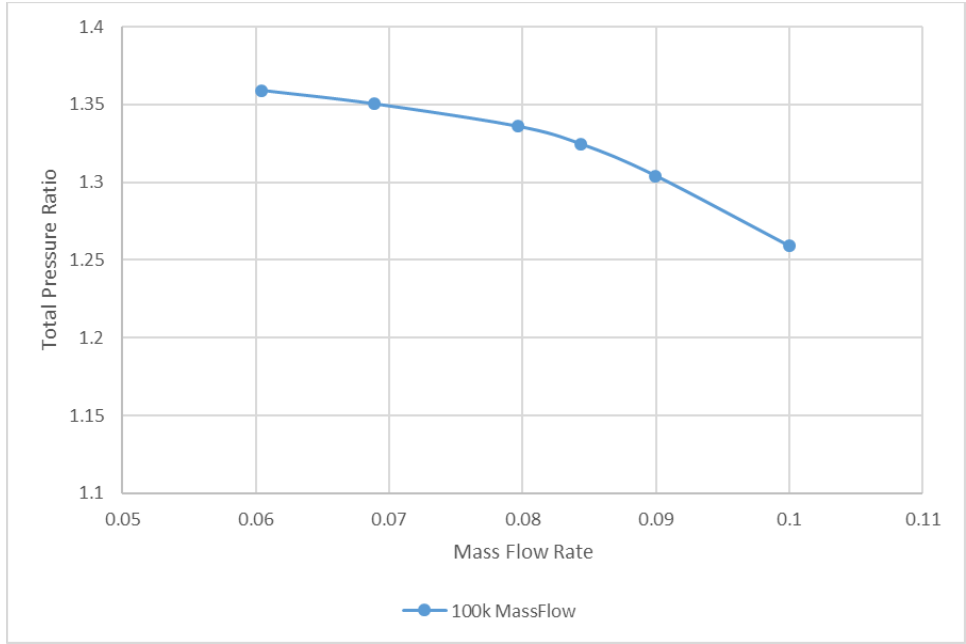


Figure 19. Total Pressure Ratio vs. Mass Flow Rate

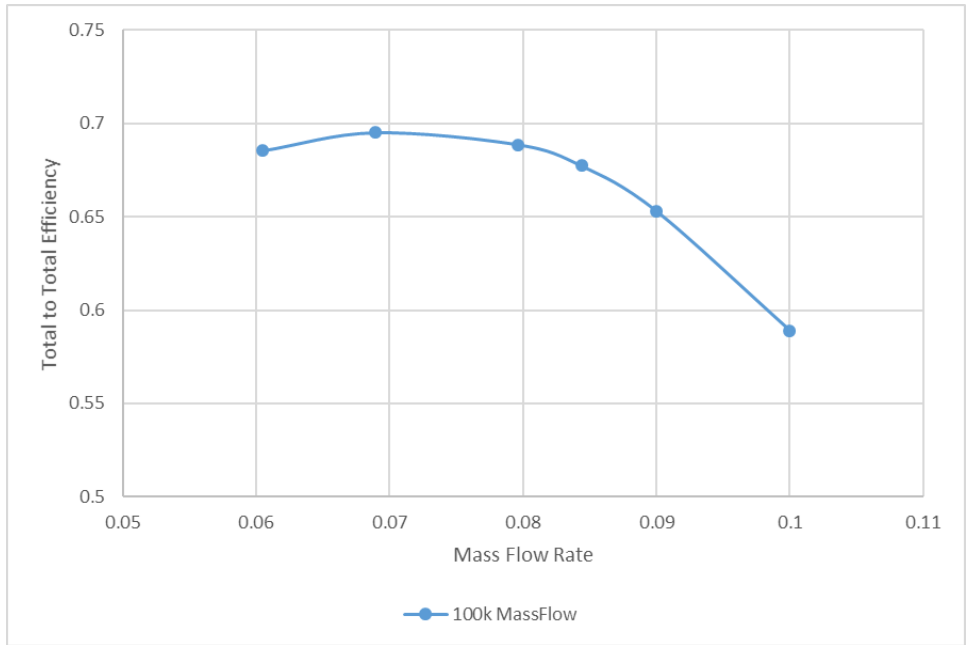


Figure 20. Total to Total Isentropic Efficiency vs. Mass Flow Rate

D. ELECTRIC MOTOR ASSEMBLY

In order to achieve 100,000 RPM, a high-speed electric motor was required. For this purpose, a Scorpion Motors HKII-2221-6 Brushless Motor was selected. This motor had a Kv value of 4,400 RPM per Volt and a rated speed of 40,000 RPM. The manufacturer suggested that the motor could be overloaded to achieve 100,000 RPM with a Cobra Wing 80A electronic speed controller. Figure 21 shows the motor and Figure 22 shows the electronic speed controller.



Figure 21. Scorpion Motor



Figure 22. Cobra Controller

An initial test of the motor was conducted to determine if 100,000 RPM could be achieved. The motor was mounted to a metal frame and was marked so the speed could be measured with a laser tachometer. During the initial test a speed of 90,000 RPM was achieved before an observer detected a burning smell and the test was halted to preserve the motor.

The motor was connected to the impeller with a shaft manufactured for that purpose. The shaft that came with the motor was used to determine dimensions for the motor side which was then modeled in SolidWorks. The end of the shaft was designed to match the shaft used in the turbocharger from where the impeller was taken. The two were combined into a single model and machined. The motor was then tested with the impeller attached using the same method as before. In this test, the impeller achieved 25,000 RPM before the shaft failed, likely due to imbalance. A modified shaft was produced to improve the strength at the point of failure, but no further tests were conducted. Figure 23 shows the full SolidWorks assembly concept including the volute, impeller, and special shaft. Figure 24 is a diagram of the shaft itself.

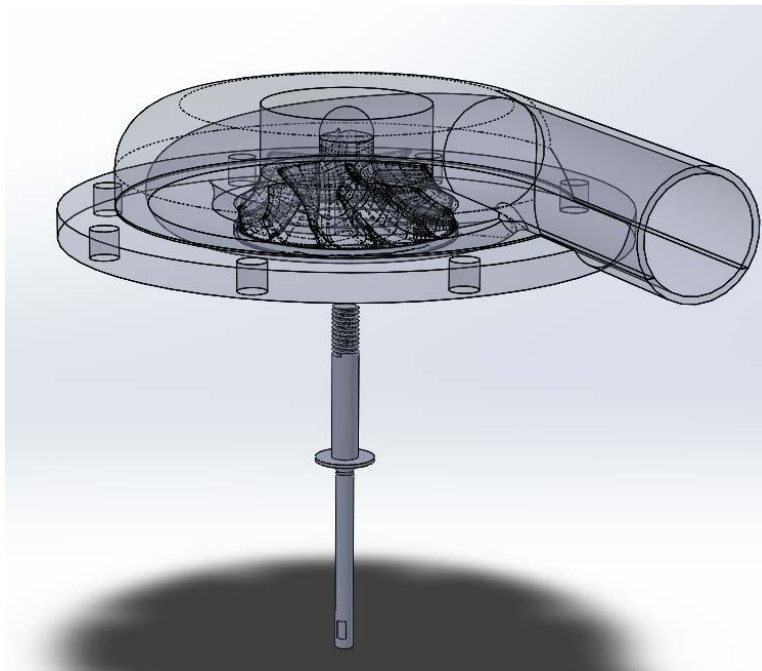


Figure 23. Assembly Model of Volute, Impeller, and Motor Shaft

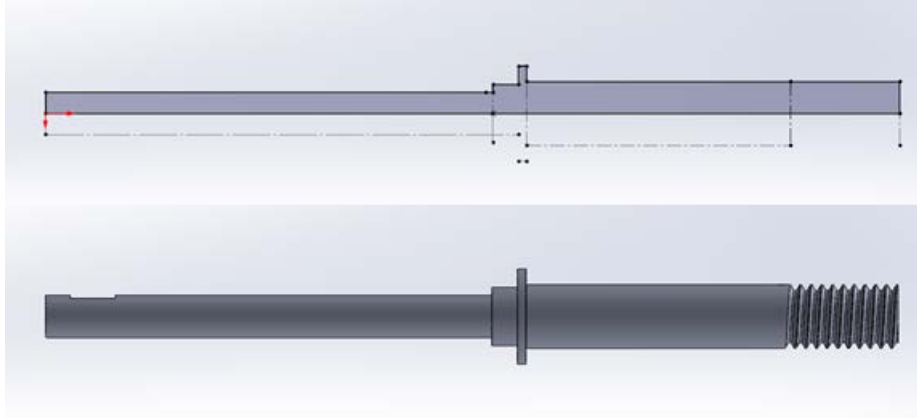


Figure 24. Motor Shaft Sketch and Model

VI. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

A. CONCLUSIONS

The work outlined in this thesis included the redesign and fabrication of two heat exchangers designed to be fit on the Allison T63-A-720 gas turbine, a new data acquisition system for pressure, temperature, and mass flow rate measurements as well as all new instrumentation. A user-friendly MATLAB code was also created to allow for modification by future users. The engine was tested with both the default exhaust configuration and the dual heat exchanger configuration in order to determine the effects of the heat exchangers on the engine's performance.

Additionally, the heat exchangers themselves were tested for the first time using nitrogen to determine the effectiveness of the heat exchanger. The effect of the heat exchanger on engine back pressure was a maximum of 2.8 kPa which resulted in a maximum power degradation of 30 kw (or -10.77%) with an associated increase in specific fuel consumption of 0.026 kg/kw-hr (or +7.25%). When operated with nitrogen gas, the heat exchanger displayed a maximum effectiveness of 71.77% with an associated increase in cold-side gas temperature of 248 K.

Finally, a prototype compressor volute was designed, fabricated via 3D printing, and analyzed using ANSYS CFX to predict its performance. The volute components, including the electric motor and commercial impeller, were assembled and tested to determine its speed capabilities.

B. FUTURE WORK

The heat exchanger manufacturing process resulted in exhaust leaks during testing. The current instrumentation rig sits directly in the exhaust leak stream, resulting in contaminated data and damage to the thermocouples and pressure taps. In order to get reliable data, this instrumentation rig will need to be moved out of the stream of the exhaust, and the exhaust leaks should be plugged. The heat exchangers should also be tested with

CO₂, and a map of heat exchanger performance with different flow types should be created to pinpoint compressor performance requirements.

The performance capabilities of the compressor volute should be further investigated for a variety of speed settings. The design of the compressor volute should also be modified as required to improve efficiency and pressure ratios, paying attention to the tongue dimensions. The volute sizing and cross section could also be modified to investigate their effect on performance. Because 3D printing is being utilized, methods for controlling swirling and outlet velocity should be investigated, such as using guide vanes and adding a diffuser shape at the outlet.

The motor shaft failed prematurely during testing. The shaft design should be reinforced and modified to achieve 100,000 RPM.

The addition of the heat exchangers to the exhaust of the T63-A-270 gas turbine resulted in backpressure which caused a considerable amount of performance degradation. The design of the heat exchanger exhaust nozzles should be modified to reduce the effect of backpressure on engine performance.

APPENDIX A. MATLAB DATA ACQUISITION SCRIPT

A. CODE DESCRIPTION

This code utilizes listeners to read temperature data in the background while gathering pressure data in the foreground. All data is stamped with a date stamp, and each data point is given a timestamp to identify it with data that was taken at the same time. All data is output via tab-delimited text files. This code was developed using work done by Belna as laid out in his thesis. This code was developed by LTJG Michael Kaim.

B. INITIALIZE

This part of the code prepares the text file output. Before running the engine, ensure the PressureBrick_Initialization.m script (section H) has been executed in order to zero the pressure bricks to the current ambient pressure.

```
% 'clearvars' is used instead of 'clear' because 's' and 'lh' are associated
% with the NI Max data acquisition system and are designed to be persistent
% variables to reduce the time it takes to start taking readings
clearvars -except s lh, clc, format compact, close all %#ok<DUALC>

% These Global variables allow temperature data to be recorded in the b
% background and indexed with their appropriate time stamp
global k
global NIdata
global time
global tch
global vch

% The 'timestampfun' embeded at the end of this script uses the number
% input to determine what to do with the data. A '1' input means the engine
% is not running and you wish to test the code. Leaving the field empty
% will record the data as if the engine is running.
[timestamp, filestamp] = timestampfun(1); %a '1' input designates test run

% The filenameer function simply checks to see if timestamped files exist,
% and if not, creates them. The outputs are the FID codes for each file.
[filenames] = filenameer(filestamp);
```

C. USER INPUTS

The “duration” input will determine how many data points the system will take during any particular speed setting. N1 and ND are set here as well to be printed on the output file. Manual input is easy, but dialogue boxes can be used as well.

```
duration = 100;

N1 = “ ____ ”
% N1 = “idle”
% N1 = string(38340)
% N1 = string(43450)
% N1 = string(48560)
% N1 = string(51120)
% N1 = string(40890)
% N1 = string(46000)
% N1 = string(51000)

ND = “ ____ ”
% ND = “idle”
% ND = string(3600)
% ND = string(4200)
% ND = string(4800)
% ND = string(5400)
% ND = string(6000)

% N1=string(inputdlg('Enter N1'))
% ND=string(inputdlg('Enter ND'))
```

D. SYSTEM SETUP

This cell initializes all data acquisition devices. The temperature code was made using the Data Acquisition Toolbox in MATLAB. The IP configuration was set up in the NI Max software. The pressure code was extracted from Matlab’s Instrument Control Toolbox.

```
% NI System
% TChannels = 15; %1 module
TChannels = 30; %2 modules
tch = 1:TChannels;
VChannels = 4; %Voltage module
channels = TChannels+VChannels;
```

```

vch = TChannel s+1: channel s;

% Locates DAQ Devices
devices = daq.getDevices;
% Create DAQ Session. If a session 's' already exists, this line of code is
% skipped in order to save time. At the beginning of the day, 'clear'
% should be run to ensure there are no variables left over from the
% previous day.
if exist('s','var')== 0
    s = daq.createSession('ni');
    % Set whether to gather data continuously or to scan a certain amount
    s.IsContinuous = true;
    % Optional code to set a specific number of scans
    % s.NumberOfScans= 20;
    % Set the data acquisition rate
    s.Rate = 1;
    % Add Thermocouple Modules to measure temperature. Modules can read 15
    % channels, and are set to read 15 thermocouples by default. Empty channels
    % and bad connections will display approximately 2500 degrees
    addAnalogInputChannel(s,'cDAQ9188XT-1CCC957Mod1',1:15,'Thermocouple');
    if TChannel s > 15
        addAnalogInputChannel(s,'cDAQ9188XT-1CCC957Mod2',1:15,'Thermocouple');
    end
    % Module 3 is for reading voltages from the Mass Flow gauges. At the time
    % of writing this code, this voltage data requires a voltage constant to
    % convert to mass flow during processing.
    addAnalogInputChannel(s,'cDAQ9188XT-1CCC957Mod4',1:4,'Voltage');
    % Set up temperature units (Required to run script)
    % s.Channels(1).ADCTimingMode = 'HighResolution';
    for i=1:TChannel s
        s.Channels(i).ThermocoupleType = 'K';
        s.Channels(i).Units = 'Kelvin';
    end
    % Create the listener which will run the input function whenever the
    % 'DataAvailable' event runs
end

% This checks for the existence of a listener variable, 'lh', and skips the
% code if it exists in order to save time.
if exist('lh','var')== 0
    lh=addlistener(s,'DataAvailable',@NI_Data);
end

% Pressure System (Code generated using Instrument Control Toolbox)
% See Belna's Thesis for more details
% Find a tcpip object.
tic
obj1 = instrfind('Type','tcpip','RemoteHost','191.30.5.147','RemotePort',23,'Tag',
'');
obj2 = instrfind('Type','tcpip','RemoteHost','191.30.5.146','RemotePort',23,'Tag',
'');
obj3 = instrfind('Type','tcpip','RemoteHost','191.30.5.148','RemotePort',23,'Tag',

```

```

'');
% Create the tcpip object if it does not exist, otherwise use the object that was found.
if isempty(obj1)
    obj1 = tcpip('191.30.5.147', 23);
else
    fclose(obj1); obj1 = obj1(1);
end
if isempty(obj2)
    obj2 = tcpip('191.30.5.146', 23);
else
    fclose(obj2); obj2 = obj2(1);
end
if isempty(obj3)
    obj3 = tcpip('191.30.5.148', 23);
else
    fclose(obj3); obj3 = obj3(1);
end
% Opens the previously specified objects and sets the parameters for each
% pressure brick
objects = [obj1; obj2; obj3];
for ii=1:3
    fopen(objects(ii));
    % Communicating with instrument object.
    fprintf(objects(ii), 'SET PERIOD 500');
    fprintf(objects(ii), 'SET AVG 32');
    % Set Frames Per Scan
    fprintf(objects(ii), 'SET FPS 1');
    % Set units to Pascals
    fprintf(objects(ii), 'SET UNITSCAN PA');
    % Set Engineering Units format
    fprintf(objects(ii), 'SET EU 1');
    % Set to ASCII data format
    fprintf(objects(ii), 'SET BIN 0');
    % Other Parameters
    fprintf(objects(ii), 'SET PERIOD 500');
    fprintf(objects(ii), 'SET AVG 32');
    fprintf(objects(ii), 'SET FORMAT 0');
    fprintf(objects(ii), 'SET TIME 0');
    % Set Buffer to clear when full and continue sending data
    fprintf(objects(ii), 'SET QPKTS 0');
end

```

E. DATA GATHERING

The Temperature gathering code runs in the background after the `s.startBackground()` code is executed. From there, the pressure readings start within the for loop. The code is designed to take the specified number of readings from the pressure bricks while continuously gathering real-time temperature data at the specified rate. Once the pressure data is collected, the Temperature process is stopped so that the readings are taken during the same interval.

```
pdata1 = zeros(duration, 16);
pdata2 = pdata1;
pdata3 = pdata1;
NIdata = zeros(1, channels);
time = 0;
k = 0;
s.startBackground();
% Takes the requested number of data points from the pressure bricks while
% running the thermocouple readings in the background
timer=0;
for i=1:duration
%   if i>1
        pause(1-timer)
%   end
    tic
    % Sends Scan Command to DSA Pressure Brick
    fprintf(obj1, 'SCAN');
    fprintf(obj2, 'SCAN');
    fprintf(obj3, 'SCAN');
    % Discards first variable from packet which lists frame number,
    % if set to FPS = 1 all frames will be 0
    frame = fscanf(obj1);
    frame = fscanf(obj2);
    frame = fscanf(obj3);
    for n=1:16
        % Extracts Pressure and Temperature readings in order # 1 to 16 ports
        data1 = str2num(fscanf(obj1));
        data2 = str2num(fscanf(obj2));
        data3 = str2num(fscanf(obj3));
        % Takes Pressure readings and discards DSA temperature readings
        pdata1(i, n)=data1(2);
        pdata2(i, n)=data2(2);
        pdata3(i, n)=data3(2);
    end
    fprintf(1, '%1.0f\n', i)
%   fprintf(1, '%2.0f\n', k);
    timer = toc;
end
```

```

pause(1)
s.stop

for ii=1:3
    % If FPS is set to 0 (infinite) this will stop pressure brick in a secure manner
    fprintf(objects(ii), 'STOP');
    % Clear input buffer
    flushinput(objects(ii));
    % Clear output buffer
    flushoutput(objects(ii));
end

```

F. OUTPUT DATA

This is where the data gets processed. The code is designed to take a specified number of readings and average them together for a single data point at the specified engine speeds. The data is then output into separate text files with the engine speed information, the unique time stamp for the data run, and the data output in a single line within their respective text files. This makes copying and pasting into excel easy with the tab delimiter specified. The first line of the text file may not line up with the data in excel since it is designed to look correct for the MATLAB text reader, and therefore may need to be modified.

```

% Split NI Data
tdata = NIdata(:, tch);
vdata = NIdata(:, vch);

% Consolidate pressure data into one variable
brick_ports = 1:16;
pdata = zeros(duration, 48);
pdata(:, brick_ports)=pdata1;
pdata(:, brick_ports+16)=pdata2;
pdata(:, brick_ports+16*2)=pdata3;
[pm, pn] = size(pdata);

% Allocate space for average variables
pave = zeros(pm, 1); pstd = pave;
tave = zeros(TChannels, 1); tstd = tave;
vave = zeros(VChannels, 1); vstd = vave;
% Calculates the average value for each port across all runs
for i = 1:pn
    pave(i, :) = mean(pdata(:, i));
    pstd(i, :) = std(pdata(:, i))./pave(i, :);

```

```

end
% Calculates the average value for each thermocouple across all runs
for i=1:Tchannels
    tave(i,:) = mean(tdata(:,i));
    tstd(i,:) = std(tdata(:,i))./tave(i,:);
end
%Calculates the average value for each voltage across all runs
for i=1:Vchannels
    vave(i,:) = mean(vdata(:,i));
    vstd(i,:) = std(vdata(:,i))./vave(i,:);
end
Text_Output_Generator(filenamees, datastamp, N1, ND, time, pave, tave, vave, pstd, tstd, vstd, NIdata
, pdata)
disp(' Run Complete ');

```

G. FUNCTIONS

This part of the code is reserved for the local functions. Local Functions must be specified at the end of the code after everything else.

```

function [datastamp, filestamp] = timestampfun(test)
% This function creates a time and date stamp for the data output files. If
% a script test run is designated, the filestamp variable is replaced with
% 'test' to output the data to a continuous testing data file. For actual
% data acquisition runs, the filestamp is the current date in YYYYMMDD
% format. The datastamp variable is the date but also includes the time at
% which the run was initiated.
% [datastamp, filestamp] = timestampfun(test)
%     where 'test' is a 1 for a script test run. Leave this field empty
%     for actual data acquisition.
if nargin == 0
    test=0;
end
% Calculate current date and time for timestamp
now = datetime('now');
y = num2str(year(now));
m = month(now);
if m<10
    m = (['0' num2str(m)]);
else
    m = num2str(m);
end
d = day(now);
if d<10
    d = (['0' num2str(d)]);
else
    d = num2str(d);

```

```

end
hr = hour(now);
if hr<10
    hr = ([ '0' num2str(hr) ]);
else
    hr = num2str(hr);
end
min = minute(now);
if min<10
    min = ([ '0' num2str(min) ]);
else
    min = num2str(min);
end
sec = round(second(now));
if sec<10
    sec = ([ '0' num2str(sec) ]);
else
    sec = num2str(sec);
end

datastamp = [y m d '_ ' hr min '_ ' sec]
if test == 1
    filestamp = 'test'
else
    filestamp = [y m d]
end
end
end

```

```

function [filenames] = filenamer(filestamp)
% Description
% This function generates the filenames for each of the output text files.
% It uses the filestamp from the previous function to ensure each file is
% dated with the YYYYMMDD date format. The output 'filenames' is a cell
% array which is an input to the text file output function. No user input
% is necessary

% File Name Generator
Pfile = [filestamp '_PressureData' '.txt'];
Tfile = [filestamp '_TemperatureData' '.txt'];
Vfile = [filestamp '_VoltageData' '.txt'];
NIdatafile = [filestamp '_NIdata' '.txt'];
Pdatafile = [filestamp '_pdata' '.txt'];
Pstd = [filestamp '_PressureStdDev' '.txt'];
Tstd = [filestamp '_TemperatureStdDev' '.txt'];
Vstd = [filestamp '_VoltageStdDev' '.txt'];
filenames = {Pfile; Tfile; Vfile; NIdatafile; Pdatafile; Pstd; Tstd; Vstd};

save('names.mat', 'Pfile', 'Tfile', 'Vfile', 'NIdatafile', 'Pdatafile', 'Pstd', 'Tstd', 'Vstd')

% File Generator
% If the file exists, this portion of the code is skipped. This would
% indicate a file with today's date is already created, and will simple be

```

```
% ammended. in the Fopen command, the 'w' indicates "write" while 'a' indicates  
% "ammend"
```

```
% Pressure File
```

```
if exist(Pfile, 'file') == 0  
    P_atm = string(inputdlg('Enter Atmospheric Pressure (with units)'));  
    % P_atm = "29.90 inHg"  
    PFID = fopen(Pfile, 'w'); % Creates a file with Pfile name.  
        % If file exists, this line is skipped.  
    fprintf(PFID, 'Atmospheric Pressure: \t%s\r', P_atm);  
    fprintf(PFID, 'Timestamp\t\t\t\t\tN1\t\tND\t\t');  
    % fprintf(PFID, '%-8.2f\t', [1.01: .01: 1.16, 2.01: .01: 2.16, 3.01: .01: 3.16]);  
    fprintf(PFID, '1_%02.0f \t', 1:16);  
    fprintf(PFID, '2_%02.0f \t', 1:16);  
    fprintf(PFID, '3_%02.0f \t', 1:16);  
    fprintf(PFID, '\r\n');  
    fclose(PFID);  
end
```

```
% Temperature File
```

```
if exist(Tfile, 'file') == 0  
    TFID = fopen(Tfile, 'w'); % Creates a file with Tfile name.  
        % If file exists, this line is skipped.  
    fprintf(TFID, 'Timestamp\t\t\t\t\tN1\t\tND\t\t');  
    fprintf(TFID, '%-8.0f\t', 1:32);  
    fprintf(TFID, '\r\n');  
    fclose(TFID);  
end
```

```
% Voltage File
```

```
if exist(Vfile, 'file') == 0  
    VFID = fopen(Vfile, 'w'); % Creates a file with Vfile name.  
        % If file exists, this line is skipped.  
    fprintf(VFID, 'Timestamp\t\t\t\t\tN1\t\tND\t\t');  
    fprintf(VFID, '%-8.0f\t', 1:10);  
    fprintf(VFID, '\r\n');  
    fclose(VFID);  
end
```

```
% Raw NI Max Data File
```

```
if exist(NIdatafile, 'file') == 0  
    TFID = fopen(NIdatafile, 'w'); % Creates a file with Tdatafile name.  
        % If file exists, this line is skipped.  
    fclose(TFID);  
end
```

```
% Raw Pressure Data File
```

```
if exist(Pdatafile, 'file') == 0  
    PFID = fopen(Pdatafile, 'w'); % Creates a file with Pdatafile name.  
        % If file exists, this line is skipped.  
    fclose(PFID);  
end
```

```

% Pressure Standard Deviation File
if exist(Pstd, 'file') == 0
    PFID2 = fopen(Pstd, 'w'); % Creates a file with Pstd name.
    % If file exists, this line is skipped.
    fprintf(PFID2, 'Timestamp\t\t\t\tN1\t\tND\t\t');
    fprintf(PFID2, '1_%02.0f\t\t\t', 1:16);
    fprintf(PFID2, '2_%02.0f\t\t\t', 1:16);
    fprintf(PFID2, '3_%02.0f\t\t\t', 1:16);
    fprintf(PFID2, '\r\n');
    fclose(PFID2);
end

```

```

% Temperature Standard Deviation File
if exist(Tstd, 'file') == 0
    TFID2 = fopen(Tstd, 'w'); % Creates a file with Tstd name.
    % If file exists, this line is skipped.
    fprintf(TFID2, 'Timestamp\t\t\t\tN1\t\tND\t\t');
    fprintf(TFID2, '%-6.0f\t\t', 1:30);
    fprintf(TFID2, '\r\n');
    fclose(TFID2);
end

```

```

% Voltage Standard Deviation File
if exist(Vstd, 'file') == 0
    VFID = fopen(Vstd, 'w'); % Creates a file with Vstd name.
    % If file exists, this line is skipped.
    fprintf(VFID, 'Timestamp\t\t\t\tN1\t\tND\t\t');
    fprintf(VFID, '%-6.0f\t\t', 1:10);
    fprintf(VFID, '\r\n');
    fclose(VFID);
end
end

```

function

```

Text_Output_Generator(filenames, datastamp, N1, ND, time, pave, tave, vave, pstd, tstd, vstd, NI data
, pdata)

```

```

% Write Data to Text File

```

```

% This function takes the data as well as each time and date stamp and
% outputs them in separate text files for processing. The text files are
% tab-delimited and formatted to be viewed in MATLAB. For MATLAB data
% processing, the files need to be formatted further by removing excess
% tab delimiters. For excel, the data needs to be imported with the import
% function or can be copied and pasted directly into excel.

```

```

% Pressure Data

```

```

Pname = (['Pdata_' datastamp]);
PFID = fopen(string(filenames(1)), 'a');
fprintf(PFID, '%s\t', Pname);
fprintf(PFID, '%s\t%s\t', [N1 ND]);
fprintf(PFID, '%08.2f\t', pave);
fprintf(PFID, '\r\n');
fclose(PFID);

```

```

% Temperature Data

```

```

Tname = (['Tdata_' datastamp]);
TFID = fopen(string(filename(2)), 'a');
fprintf(TFID, '%s\t', Tname);
fprintf(TFID, '%s\t%s\t', [N1 ND]);
fprintf(TFID, '%-010.4f\t', tave);
fprintf(TFID, '\r\n');
fclose(TFID);

% Voltage Data
Vname = (['Vdata_' datastamp]);
VFID = fopen(string(filename(3)), 'a');
fprintf(VFID, '%s\t', Vname);
fprintf(VFID, '%s\t%s\t', [N1 ND]);
fprintf(VFID, '%-010.4f\t', vave);
fprintf(VFID, '\r\n');
fclose(VFID);

% Raw NI Values
Tname = (['Trawdata_' datastamp]);
[m, n] = size(NIdata);
TFID = fopen(string(filename(4)), 'a');
fprintf(TFID, '%s\t', Tname);
fprintf(TFID, 'N1: %s\tND: %s\t\ntime\t', [N1 ND]);
fprintf(TFID, '%-10.0f\t', 1:n);
fprintf(TFID, '\n');
for i=1:m
    fprintf(TFID, '%2.2f\t', time(i));
    fprintf(TFID, '%-06.4f\t', NIdata(i, 1:n));
    fprintf(TFID, '\r');
end
fprintf(TFID, '\n');
fclose(TFID);

% Raw Pressure Values
Pname = (['Prawdata_' datastamp]);
[m, n] = size(pdata);
PFID = fopen(string(filename(5)), 'a');
fprintf(PFID, '%s\t', Pname);
fprintf(PFID, 'N1: %s\tND: %s\t\n', [N1 ND]);
% fprintf(PFID, '%-6.4f\t', [1.01:.01:1.16, 2.01:.01:2.16, 3.01:.01:3.16]);
fprintf(PFID, '1_%02.0f \t', 1:16);
fprintf(PFID, '2_%02.0f \t', 1:16);
fprintf(PFID, '3_%02.0f \t', 1:16);
fprintf(PFID, '\n');
for i=1:m
    fprintf(PFID, '%010.2f\t', pdata(i, 1:n));
    fprintf(PFID, '\r');
end
fprintf(PFID, '\n');
fclose(PFID);

% Pressure Standard Deviation
Pname = (['Pstd_' datastamp]);
PFID = fopen(string(filename(6)), 'a');

```

```

fprintf(PFID, '%s\t', Pname);
fprintf(PFID, '%s\t%s\t', [N1 ND]);
fprintf(PFID, '%08.4G%\t', pstd. *100);
fprintf(PFID, '\r\n');
fclose(PFID);
% Temperature Standard Deviation
Tname = ([ 'Tstd_' datastamp]);
TFID = fopen(string(filename(7)), 'a');
fprintf(TFID, '%s\t', Tname);
fprintf(TFID, '%s\t%s\t', [N1 ND]);
fprintf(TFID, '%-2.4f%\t', tstd. *100);
fprintf(TFID, '\r\n');
fclose(TFID);
% Voltage Standard Deviation
Vname = ([ 'Vstd_' datastamp]);
VFID = fopen(string(filename(8)), 'a');
fprintf(VFID, '%s\t', Vname);
fprintf(VFID, '%s\t%s\t', [N1 ND]);
fprintf(VFID, '%-2.2f%\t', vstd. *100);
fprintf(VFID, '\r\n');
fclose(VFID);
end

```

[Published with MATLAB® R2018b](#)

H. PRESSURE BRICK INITIALIZATION CODE

Run this script to initialize and zero the pressure bricks. Do not run this script while the engine is running and collecting data as it will zero the measurements to the current readings. The key line in this code which zeros the pressure bricks is the last one, sending the fprintf command with 'CALZ' causes the zeroing. For more information, see Belna's thesis.

```

clc, clear
obj1 = instrfind('Type', 'tcpip', 'RemoteHost', '191.30.5.147', 'RemotePort', 23, 'Tag', '');
obj2 = instrfind('Type', 'tcpip', 'RemoteHost', '191.30.5.146', 'RemotePort', 23, 'Tag', '');
obj3 = instrfind('Type', 'tcpip', 'RemoteHost', '191.30.5.148', 'RemotePort', 23, 'Tag', '');
% Create the tcpip object if it does not exist, otherwise use the object that was found.
if isempty(obj1)
    obj1 = tcpip('191.30.5.147', 23);
else
    fclose(obj1); obj1 = obj1(1);
end

```

```

if isempty(obj2)
    obj2 = tcpip('191.30.5.146', 23);
else
    fclose(obj2); obj2 = obj2(1);
end
if isempty(obj3)
    obj3 = tcpip('191.30.5.148', 23);
else
    fclose(obj3); obj3 = obj3(1);
end
% Opens the previously specified objects and sets the parameters for each
% pressure brick
objects = [obj1; obj2; obj3];

for ii=1:3
    fopen(objects(ii));
    % Communicating with instrument object.
    fprintf(objects(ii), 'SET PERIOD 500');
    fprintf(objects(ii), 'SET AVG 32');
    % Set Frames Per Scan
    fprintf(objects(ii), 'SET FPS 1');
    % Set units to Pascals
    fprintf(objects(ii), 'SET UNITSCAN PA');
    % Set Engineering Units format
    fprintf(objects(ii), 'SET EU 1');
    % Set to ASCII data format
    fprintf(objects(ii), 'SET BIN 0');
    % Other Parameters
    fprintf(objects(ii), 'SET PERIOD 500');
    fprintf(objects(ii), 'SET AVG 32');
    fprintf(objects(ii), 'SET FORMAT 0');
    fprintf(objects(ii), 'SET TIME 0');
    % Set Buffer to clear when full and continue sending data
    fprintf(objects(ii), 'SET QPKTS 0');
    fprintf(objects(ii), 'CALZ');
end

```

I. NATIONAL INSTRUMENTS LISTENER FUNCTION

This is the listener function that actually runs with the DAQ system. The key to this function is the “event” variable. Timesteps can be extracted using the “event.TimeStamps” variable and data can be extracted by the “event.Data” variable. The DAQ system relies on global variables to transfer the data from this function to the main program. “k” is used to sequentially add rows to the existing data. All global variables are defined in the main script.

```

function NI_Data(src, event)

global k
global NIdata
global time
global tch
global vch

k=k+1;
% Reads temperature data from modules
time(k,:) = event.TimeStamps;
NIdata(k,:) = event.Data;

% This part of the code simply prints the current data to the command
% window for troubleshooting. Everything after this comment can be safely
% commented out or removed without affecting execution.
tdata = NIdata(k, tch);
vdata = NIdata(k, vch);
fprintf(1, 'Temp\t|')
fprintf(1, '%-6.0f\t', 1:15)
fprintf(1, '\r')
fprintf(1, '%4.1f\t|', time(k))
fprintf(1, '%4.2f\t', tdata(1:15))
fprintf(1, '\r\t\t')
fprintf(1, '%-6.0f\t', 16:30)
fprintf(1, '\r\t\t')
fprintf(1, '%4.2f\t', tdata(16:30))
fprintf(1, '\rVoltage\t')
fprintf(1, '%-6.0f\t', 1:4)
fprintf(1, '\r\t\t')
fprintf(1, '%1.4f\t', vdata)
fprintf(1, '\r')
end

```

APPENDIX B. INSTRUMENTATION PORTS

This section is primarily for the table of ports which correspond to the raw data contained in the following appendix.

A. PRESSURE BRICK INSTRUMENTATION

Note: cold side measurements were not added until after the 20190510 run. These ports should be discarded as if they were empty.

Port	(1) 10" H2O	(2) 2.5 PSID	(3) 100 PSID
1	Compressor Inlet Static	Compressor Inlet Static	Compressor Inlet Static
2	Compressor Inlet Total	Compressor Inlet Total	Compressor Inlet Total
3			Compressor Outlet Left
4			Compressor Outlet Right
5			Cold Side Inlet
6			Cold Side Outlet
7	Left Stack 1	Left Stack 1	Left Stack 1
8	Right Stack 1	Right Stack 1	Right Stack 1
9	Left Stack 0	Left Stack 0	Left Stack 0
10	Right Stack 0	Right Stack 0	Right Stack 0
11	Left Stack 2	Left Stack 2	Left Stack 2
12	Right Stack 2	Right Stack 2	Right Stack 2
13	Left Stack 3	Left Stack 3	Left Stack 3
14	Right Stack 3	Right Stack 3	Right Stack 3
15	Left Stack 4	Left Stack 4	Left Stack 4
16	Right Stack 4	Right Stack 4	Right Stack 4

B. THERMOCOUPLE INSTRUMENTATION

Note: heat exchanger thermocouples were not added until after 20190510, and therefore those channels should be ignored.

TC	Location
1	Compressor Inlet 1
2	Compressor Inlet 2
3	Compressor Outlet Left
4	Compressor Outlet Right
5	T5
6	Left Stack 1
7	Left Stack 2
8	Right Stack 1
9	Right Stack 2
10	Left Stack 3
11	
12	
13	Right Stack 3
14	HE_Hot_in
15	HE_Hot_out
16	4"-in
17	6"-in
18	8"-in
19	10"-in
20	4"-out
21	6"-out
22	8"-out
23	10"-out

APPENDIX C. RAW MATLAB DATA

All pressure data is reported in Pascals. All temperature data is reported in Kelvin. Standard Deviations are provided, initially in absolute units and later in relative. Relative standard deviations are reported with a percent sign to make this clear.

For pressure bricks, a measurement that is out of range will be reported as -999999. For temperatures, empty channels as well as bad thermocouples will read as approximately 2500. These measurements should be discarded completely, and any channel that failed mid-run was not used for this thesis. Standard deviation was used to determine if a thermocouple was bad or if a measurement was on the edge of a pressure brick's range. A good measurement will have a low standard deviation and a reasonable value.

A. 20190130: STANDARD CONFIGURATION

N1	ND	Atmospheric Pressure: File Name	29.95 inHg															
			1_01	1_02	1_03	1_04	1_05	1_06	1_07	1_08	1_09	1_10	1_11	1_12	1_13	1_14	1_15	1_16
idle	idle	Pdata_20190130_1232_49	-999999	-256	-21	-21	-21	-22	169	78	220	-31	-58	34	-4	3	-65	-16
40890	3600	Pdata_20190130_1234_59	-999999	-473	-24	-24	-24	-22	69	-10	142	429	-131	45	165	69	-251	27
40890	4200	Pdata_20190130_1236_44	-999999	-475	-25	-24	-25	-24	184	37	378	209	-163	64	139	69	-230	14
40890	4200	Pdata_20190130_1237_08	-999999	-475	-24	-24	-25	-24	192	39	383	211	-168	63	129	66	-234	15
40890	4800	Pdata_20190130_1239_56	-999999	-477	-25	-24	-27	-25	235	94	542	93	-177	85	137	63	-185	1
40890	4800	Pdata_20190130_1241_24	-999999	-478	-25	-26	-26	-27	183	57	504	153	-172	76	147	70	-199	2
40890	4800	Pdata_20190130_1241_40	-999999	-477	-27	-26	-26	-25	184	58	505	158	-176	75	142	68	-196	3
40890	5400	Pdata_20190130_1243_21	-999999	-480	-28	-27	-26	-28	278	135	411	33	-130	86	117	45	-163	-7
40890	5400	Pdata_20190130_1243_37	-999999	-481	-28	-29	-28	-28	276	137	386	30	-125	84	102	41	-165	-9
40890	6000	Pdata_20190130_1244_56	-999999	-483	-31	-31	-31	-29	394	195	493	-35	-123	98	42	20	-145	-18
40890	6000	Pdata_20190130_1245_12	-999999	-482	-31	-30	-31	-29	395	196	485	-36	-124	98	33	17	-144	-18
46000	6000	Pdata_20190130_1246_56	-999999	-631	-32	-32	-32	-32	267	67	746	352	-324	130	323	134	-370	25
46000	6000	Pdata_20190130_1247_12	-999999	-629	-31	-29	-29	-30	288	75	756	360	-316	132	226	128	-377	25
46000	5400	Pdata_20190130_1249_20	-999999	-631	-31	-29	-28	-29	331	62	533	483	-310	117	148	102	-427	35
46000	5400	Pdata_20190130_1249_36	-999999	-631	-29	-31	-32	-30	328	56	526	484	-314	118	246	99	-432	37
46000	5400	Pdata_20190130_1250_14	-999999	-630	-33	-32	-31	-32	314	54	563	448	-303	113	141	108	-417	33
46000	4800	Pdata_20190130_1252_43	-999999	-621	-30	-28	-29	-29	142	5	264	746	-246	91	198	117	-400	53
46000	4800	Pdata_20190130_1253_01	-999999	-619	-27	-28	-28	-27	153	9	256	729	-246	91	111	116	-397	52
46000	4200	Pdata_20190130_1255_31	-999999	-624	-25	-25	-26	-25	123	9	82	500	-237	79	301	155	-528	72
46000	4200	Pdata_20190130_1255_47	-999999	-625	-28	-28	-27	-28	120	4	86	493	-230	77	302	154	-520	70
46000	3600	Pdata_20190130_1256_50	-999999	-633	-27	-28	-29	-28	210	71	98	-347	-191	68	144	115	-594	81
46000	3600	Pdata_20190130_1257_05	-999999	-629	-27	-26	-26	-27	203	68	80	-305	-189	71	154	121	-583	81
51000	3600	Pdata_20190130_1259_02	-999999	-912	-34	-33	-32	-33	330	139	72	-1024	-149	78	277	197	-1427	161
51000	3600	Pdata_20190130_1259_18	-999999	-910	-30	-33	-32	-35	337	149	73	-997	-147	92	255	204	-1409	159
51000	4200	Pdata_20190130_1300_28	-999999	-913	-34	-32	-33	-32	423	194	87	-1176	-234	111	287	196	-1072	143
51000	4200	Pdata_20190130_1300_46	-999999	-915	-31	-30	-32	-33	423	193	92	-1149	-243	104	93	186	-1092	140
51000	4800	Pdata_20190130_1301_59	-999999	-919	-33	-35	-34	-33	376	145	169	-818	-284	119	229	230	-1700	138
51000	4800	Pdata_20190130_1302_14	-999999	-922	-34	-33	-34	-35	367	140	168	-898	-288	117	333	234	-1827	136
51000	5400	Pdata_20190130_1303_30	-999999	-917	-34	-35	-34	-34	255	59	58	3	-363	130	417	252	-893	127
51000	5400	Pdata_20190130_1303_46	-999999	-918	-33	-33	-31	-32	256	65	74	-127	-367	137	428	254	-905	127
51000	6000	Pdata_20190130_1304_37	-999999	-924	-35	-35	-36	-34	240	15	367	979	-412	146	406	251	-786	116
51000	6000	Pdata_20190130_1304_52	-999999	-923	-36	-33	-31	-33	239	13	390	998	-410	149	333	250	-801	111
51000	6000	Pdata_20190130_1305_07	-999999	-919	-39	-34	-34	-35	235	6	400	1062	-412	145	338	247	-783	108

N1	ND	File Name	1_01	1_02	1_03	1_04	1_05	1_06	1_07	1_08	1_09	1_10	1_11	1_12	1_13	1_14	1_15	1_16
idle	idle	Pstd_20190130_1232_49	0	2.78	3.08	2.67	2.84	2.42	3.63	3.31	13.56	8.31	3.16	1.97	19.82	6.03	4.76	2.74
40890	3600	Pstd_20190130_1234_59	0	2.93	4.38	3.99	4.12	3.7	16.38	10.07	29.13	28.69	3.34	3.82	8.25	7.98	11.5	2.63
40890	4200	Pstd_20190130_1236_44	0	2.78	3.7	3.31	4.02	3.27	15.43	9.33	36.9	30.84	5.56	3.19	7.95	7.8	11.06	2.29
40890	4200	Pstd_20190130_1237_08	0	3.07	4.96	4.49	3.29	3.7	19.81	13.09	38.93	28.9	5.16	3.2	8.57	6.78	11.11	2.42
40890	4800	Pstd_20190130_1239_56	0	2.99	4.85	3.6	4.87	4.08	39.42	27.32	78.19	54.69	13.69	5.07	17.11	13	14	3.23
40890	4800	Pstd_20190130_1241_24	0	2.16	3.85	3.58	3.61	5.01	11.44	8.15	34.01	14.51	4.48	2.63	8.15	8.22	7.11	2.25
40890	4800	Pstd_20190130_1241_40	0	2.13	3.67	4.56	4.08	4.5	17.5	11.4	33.83	13.39	5.77	2.53	11.84	8.01	6.26	2.45
40890	5400	Pstd_20190130_1243_21	0	2.27	4.32	3.21	3.73	5.22	8.31	5.56	45.54	12.77	7.48	3.46	5.36	4.49	9.17	2.11
40890	5400	Pstd_20190130_1243_37	0	2.12	3.22	3.53	4.33	4.35	11.69	7.42	75.14	13.34	9.35	4.82	19.67	6.21	8.49	2.77
40890	6000	Pstd_20190130_1244_56	0	2.14	4.49	5.37	5	3.81	6.88	3.88	36.49	10.54	4.73	1.84	18.97	5.85	6.7	2.42
40890	6000	Pstd_20190130_1245_12	0	1.98	5.15	5.11	3.08	4.5	4.53	6.48	26.58	15.18	5.48	2.5	16.19	4.01	6.75	1.64
46000	6000	Pstd_20190130_1246_56	0	3.01	5.51	4.13	3.94	4.46	41.3	18.49	54.42	31.55	11.2	5.53	20.01	12.45	11.45	4.75
46000	6000	Pstd_20190130_1247_12	0	2.84	4.67	3.49	3.8	5.94	31.71	15.14	73.91	28.93	10.07	3.78	30.3	11.79	12.15	4.73
46000	5400	Pstd_20190130_1249_20	0	3.12	3.75	3.67	5.2	3.36	18.85	12.17	60.49	54.9	8.67	4.53	61.05	10.09	16.19	2.39
46000	5400	Pstd_20190130_1249_36	0	2.35	3.08	3.61	3.89	3.01	18.78	13.32	38.31	56.43	7	5.1	14.58	10.87	16.7	3.18
46000	5400	Pstd_20190130_1250_14	0	2.6	4.45	4.16	4	4.07	19.72	16.18	51.71	56.9	9.21	3.64	31.82	8.14	17.64	4.58
46000	4800	Pstd_20190130_1252_43	0	2.89	3.66	4.04	3.05	2.15	22.29	13.57	49.15	45.91	4.89	3.42	29.44	8.39	13.42	3.33
46000	4800	Pstd_20190130_1253_01	0	2.48	4.64	4.45	3.73	2.85	26.63	12.91	50.07	28.37	9.06	4.19	44.26	11.3	17.01	3.21
46000	4200	Pstd_20190130_1255_31	0	3.6	3.92	3.83	3.47	3.45	9.94	8.17	26.79	57.82	6.05	4.47	22.15	12.81	16.52	3.84
46000	4200	Pstd_20190130_1255_47	0	2.93	3.75	4.43	3.24	3.06	15.9	10.86	30.26	85.95	8.62	4.2	16.2	12.6	21.35	4.03
46000	3600	Pstd_20190130_1256_50	0	4.69	3.22	5.41	5.4	3.67	8.25	6.79	34.94	126.23	7.47	4.4	13.73	16.1	16.39	3.47
46000	3600	Pstd_20190130_1257_05	0	2.97	4.32	3.17	4.96	4.34	6.94	5.68	25.11	67.17	8.37	3.5	39.3	9.91	21.21	4.69
51000	3600	Pstd_20190130_1259_02	0	3.62	8.03	5.94	7.9	7.12	8.43	9.29	30.97	86.36	7.73	6.12	61.13	16.63	31.05	7.82
51000	3600	Pstd_20190130_1259_18	0	3.45	9.82	7.33	9.13	8.21	11.02	10.97	26.74	107.02	8.76	6.32	241.67	23.62	41.41	11.38
51000	4200	Pstd_20190130_1300_28	0	4.73	7.38	5.73	8.11	5.37	11.03	10.84	33.82	119.51	11.17	5.94	82.21	14.48	23.11	9.11
51000	4200	Pstd_20190130_1300_46	0	5.77	5.41	9.06	6.33	7.38	8.46	7.51	35.11	78.39	9.99	8.68	50.42	12.08	34.81	8.21
51000	4800	Pstd_20190130_1301_59	0	3.76	7.5	5.35	7.41	5.8	15.7	11.79	51.55	136.66	7.7	9	55.6	20.03	143.14	6.19
51000	4800	Pstd_20190130_1302_14	0	3.58	8.25	5.93	7.1	8.2	12.36	10.46	45.17	100.12	10.4	9.79	50.41	14.37	62.02	4.54
51000	5400	Pstd_20190130_1303_30	0	4.15	7.17	5.63	6.88	5.5	13.87	13.82	36.63	169.65	11.56	8.18	39.32	12.9	26.56	6.6
51000	5400	Pstd_20190130_1303_46	0	2.64	6.84	6.06	6.02	5.39	14.24	11.32	38.54	192.72	14.47	7.25	69.83	16.16	23.11	5.69
51000	6000	Pstd_20190130_1304_37	0	3.26	6.82	9.12	7.18	6.38	20.43	18.99	52.86	149.48	15.27	8.39	66.31	17.09	20.4	5.98
51000	6000	Pstd_20190130_1304_52	0	3.32	5.93	9.13	6.45	7.93	20.38	21.88	56.16	125.73	13.28	9.17	57.84	10.31	24.07	5.77
51000	6000	Pstd_20190130_1305_07	0	3.4	9.38	4.6	6.6	7.03	21.2	15.77	65.92	163.49	16.86	9.06	26.37	18.51	26.01	5.62

N1	ND	File Name	2_01	2_02	2_03	2_04	2_05	2_06	2_07	2_08	2_09	2_10	2_11	2_12	2_13	2_14	2_15	2_16
idle	idle	Pdata_20190130_1232_49	-3545	-257	-20	-21	-22	-22	163	74	217	-36	-60	31	-8	-1	-71	-20
40890	3600	Pdata_20190130_1234_59	-7030	-475	-23	-24	-25	-25	63	-15	139	426	-135	41	162	65	-256	24
40890	4200	Pdata_20190130_1236_44	-7025	-477	-25	-26	-27	-26	178	33	375	202	-167	60	136	66	-236	10
40890	4200	Pdata_20190130_1237_08	-7042	-477	-24	-25	-26	-26	187	35	381	205	-171	61	126	63	-241	11
40890	4800	Pdata_20190130_1239_56	-7011	-479	-27	-26	-26	-29	230	90	539	87	-181	81	134	61	-191	-3
40890	4800	Pdata_20190130_1241_24	-6973	-480	-27	-27	-28	-29	177	53	503	148	-176	72	143	67	-205	-3
40890	4800	Pdata_20190130_1241_40	-6961	-479	-27	-28	-28	-28	178	54	505	153	-180	71	139	64	-202	-2
40890	5400	Pdata_20190130_1243_21	-6983	-482	-27	-29	-29	-28	273	131	408	28	-133	83	113	42	-168	-11
40890	5400	Pdata_20190130_1243_37	-6986	-483	-29	-30	-30	-29	270	134	384	24	-128	82	98	38	-171	-14
40890	6000	Pdata_20190130_1244_56	-6973	-486	-31	-33	-33	-32	389	192	495	-40	-126	95	39	16	-150	-23
40890	6000	Pdata_20190130_1245_12	-6964	-485	-31	-32	-31	-33	390	192	483	-40	-127	96	29	13	-149	-23
46000	6000	Pdata_20190130_1246_56	-9210	-634	-33	-32	-31	-33	262	62	751	345	-328	127	319	129	-376	21
46000	6000	Pdata_20190130_1247_12	-9190	-632	-30	-30	-33	-33	283	70	755	355	-320	130	222	123	-384	21
46000	5400	Pdata_20190130_1249_20	-9116	-634	-31	-30	-30	-34	326	58	532	474	-314	113	144	98	-434	32
46000	5400	Pdata_20190130_1249_36	-9125	-633	-32	-31	-32	-32	323	52	521	481	-318	115	242	95	-438	34
46000	5400	Pdata_20190130_1250_14	-9035	-632	-33	-33	-33	-35	309	50	563	445	-307	110	137	103	-425	30
46000	4800	Pdata_20190130_1252_43	-8928	-624	-28	-29	-31	-32	136	1	265	742	-249	88	193	113	-407	50
46000	4800	Pdata_20190130_1253_01	-8899	-621	-27	-27	-30	-29	148	5	258	722	-249	88	107	112	-404	49
46000	4200	Pdata_20190130_1255_31	-8987	-627	-28	-28	-27	-27	118	4	76	494	-241	75	297	151	-533	69
46000	4200	Pdata_20190130_1255_47	-8962	-627	-29	-29	-30	-31	115	0	86	483	-234	73	298	150	-525	67
46000	3600	Pdata_20190130_1256_50	-9086	-636	-28	-30	-30	-28	205	66	96	-357	-194	64	140	111	-599	78
46000	3600	Pdata_20190130_1257_05	-9020	-632	-28	-28	-27	-30	198	63	82	-303	-193	66	150	116	-589	78
51000	3600	Pdata_20190130_1259_02	-13170	-914	-31	-34	-33	-35	325	135	73	-1022	-151	74	272	194	-1436	159
51000	3600	Pdata_20190130_1259_18	-13072	-911	-30	-33	-37	-35	331	143	76	-995	-150	88	251	200	-1417	158
51000	4200	Pdata_20190130_1300_28	-12841	-915	-31	-34	-36	-33	417	190	95	-1173	-238	105	282	192	-1079	140
51000	4200	Pdata_20190130_1300_46	-12840	-917	-32	-32	-35	-36	418	188	92	-1148	-246	98	89	181	-1099	137
51000	4800	Pdata_20190130_1301_59	-12771	-921	-35	-37	-35	-33	371	140	167	-840	-287	115	224	226	-1709	135
51000	4800	Pdata_20190130_1302_14	-12775	-925	-33	-37	-37	-34	362	135	167	-904	-292	112	328	229	-1838	134
51000	5400	Pdata_20190130_1303_30	-12580	-919	-35	-36	-36	-33	250	54	56	1	-366	125	413	247	-900	125
51000	5400	Pdata_20190130_1303_46	-12593	-921	-31	-32	-34	-35	250	60	73	-121	-369	132	424	249	-912	126
51000	6000	Pdata_20190130_1304_37	-12608	-926	-33	-36	-37	-38	235	10	372	974	-414	143	403	246	-793	113
51000	6000	Pdata_20190130_1304_52	-12568	-925	-31	-35	-36	-36	233	7	389	991	-413	145	330	246	-807	108
51000	6000	Pdata_20190130_1305_07	-12517	-922	-35	-36	-37	-38	230	1	400	1054	-414	141	334	243	-788	106

N1	ND	File Name	2_01	2_02	2_03	2_04	2_05	2_06	2_07	2_08	2_09	2_10	2_11	2_12	2_13	2_14	2_15	2_16
idle	idle	Pstd_20190130_1232_49	15.8	2.58	1.98	2.62	2.12	1.9	3.75	3.3	12.95	7.8	3.46	2.02	19.73	6.17	4.57	2.7
40890	3600	Pstd_20190130_1234_59	11.18	2.9	2.67	3.81	3.57	3.13	16.48	9.55	27.42	26.01	3.48	3.48	8.33	7.58	11.39	2.87
40890	4200	Pstd_20190130_1236_44	30.21	2.72	3.23	2.7	4.39	3.09	15.6	9.48	35.94	29.84	5.88	3.04	8.23	7.2	10.84	2.42
40890	4200	Pstd_20190130_1237_08	28.08	3.34	2.96	2.98	3.28	2.91	19.7	13.02	37.25	28.71	5.22	3.25	8.57	7.25	10.9	2.7
40890	4800	Pstd_20190130_1239_56	15.23	3.02	4.01	3.3	3.25	2.93	39.59	27.41	77.59	54.49	13.99	4.94	17.24	13.07	13.89	2.97
40890	4800	Pstd_20190130_1241_24	7.98	1.94	3.96	3.35	2.96	2.88	11.04	8.03	29.76	13.78	4.53	3.02	8.24	8.38	7.3	2.32
40890	4800	Pstd_20190130_1241_40	10.94	2.25	2.55	3.11	2.86	2.71	17.69	11.29	33.97	12.32	5.87	2.51	12.1	7.88	6.46	2.83
40890	5400	Pstd_20190130_1243_21	13.11	2.34	3.11	2.71	3.66	4.22	8.25	5.09	49.59	13.02	7.6	3.37	5.32	4.23	8.84	2.56
40890	5400	Pstd_20190130_1243_37	11.98	1.72	3.52	2.47	4.99	2.75	11.77	7.6	75.9	12.56	9.5	4.74	19.66	6.39	8.4	3.26
40890	6000	Pstd_20190130_1244_56	12.95	2.33	3.29	2.95	3.01	3.41	6.94	3.6	31.62	10.26	4.87	1.8	19.54	5.31	6.56	2.39
40890	6000	Pstd_20190130_1245_12	10.77	2.22	3.33	4.38	3.29	2.91	4.84	5.74	26.59	14.88	5.78	2.4	16.27	4.11	6.78	1.89
46000	6000	Pstd_20190130_1246_56	17.42	3.38	3.91	4.76	4.54	3.76	41.41	18.42	50.33	30.36	11.19	5.56	19.93	12.45	11.98	5.03
46000	6000	Pstd_20190130_1247_12	19.77	2.68	4.56	4.28	4.06	3.65	31.17	14.99	64.43	26.29	10.3	4.14	30.64	12.53	12.03	4.64
46000	5400	Pstd_20190130_1249_20	21.01	2.99	3.22	4.68	3.58	5.04	19.07	12.07	61.75	57.3	8.82	4.41	61.24	10.39	15.95	2.31
46000	5400	Pstd_20190130_1249_36	17.14	2.35	4.38	3.27	4.18	3.88	18.91	13.81	38.13	60.96	6.86	4.75	14.33	10.47	16.25	3.43
46000	5400	Pstd_20190130_1250_14	15.8	3.21	4.82	4.28	4.02	4.04	19.83	15.81	46.24	58.67	9.46	3.52	31.61	8.5	17	4.44
46000	4800	Pstd_20190130_1252_43	16.47	3.22	4.19	2.92	3.69	2.8	22.41	13.87	43.5	43.42	4.78	3.21	29.65	8.12	13.49	3.49
46000	4800	Pstd_20190130_1253_01	20.16	2.86	3.48	3.56	3.2	3.79	26.89	12.98	57.3	27.64	9	4.26	44.31	11.27	17.17	3.06
46000	4200	Pstd_20190130_1255_31	14.36	3.79	5.41	4.4	3.96	3.26	10.28	7.93	22.01	55.78	6.06	4.2	22.03	13.01	16.91	4.06
46000	4200	Pstd_20190130_1255_47	16.98	3.58	4.64	4.58	3.99	3.62	15.86	10.84	28.28	86.37	8.63	4.14	16.3	12.46	21.44	4.31
46000	3600	Pstd_20190130_1256_50	54.11	4.66	4.08	4.87	4.71	4.56	8.12	7.42	28.8	120.49	7.31	4.07	14.02	16.71	16.37	3.6
46000	3600	Pstd_20190130_1257_05	20.91	3.29	4.64	2.67	5.42	3.26	7.03	5.8	24.3	72.48	8.62	3.46	39.42	9.96	21.35	4.94
51000	3600	Pstd_20190130_1259_02	29.28	3.59	7.84	8.55	10.69	7.6	8.28	9.56	25.04	93.77	7.84	6.67	61.65	17.05	31.09	7.18
51000	3600	Pstd_20190130_1259_18	45.39	3.01	10.22	8.54	9.56	7.94	10.76	10.57	33.09	101.05	8.65	6.49	241.52	23.62	41.95	12.41
51000	4200	Pstd_20190130_1300_28	69	4.79	7.85	8.03	7.18	8.6	11.16	10.98	30.21	98.69	11.36	6.1	81.95	14.18	23.62	9.67
51000	4200	Pstd_20190130_1300_46	55.26	5.36	8.37	7.39	10.61	6.92	8.32	7.04	35.28	79.53	9.89	9.13	50.31	11.46	34.73	8.32
51000	4800	Pstd_20190130_1301_59	20.09	3.62	4.29	5.37	6.35	7.2	15.89	11.99	49.48	130.5	7.77	9.04	55.71	19.88	143.97	5.65
51000	4800	Pstd_20190130_1302_14	16.28	3.01	5.45	6.68	8.7	8.37	12.23	10.05	37.25	97.7	10.54	9.89	50.96	14	61.95	4.08
51000	5400	Pstd_20190130_1303_30	32.35	3.88	6.09	6.79	7.59	6.76	13.9	13.65	35.04	159.1	11.04	7.8	39.45	12.93	27.01	5.99
51000	5400	Pstd_20190130_1303_46	18.37	3.23	6.07	6.02	6.33	7.03	14.57	11.4	30.13	191.22	14.17	7.11	69.83	16.68	23.51	4.82
51000	6000	Pstd_20190130_1304_37	13.83	3.17	6.4	7.58	7.14	6.35	20.68	19.12	55.77	149.21	15.46	8.26	66.65	16.43	20.59	5.8
51000	6000	Pstd_20190130_1304_52	27.82	3.32	6.25	8.27	8.76	7.28	20.66	22.06	51.46	120.07	13.41	8.87	57.73	9.72	24.12	5.32
51000	6000	Pstd_20190130_1305_07	25.85	3.42	6.64	5.06	8.29	6.17	21.14	16.27	66.15	164.53	16.75	9.34	26.51	18.7	25.08	5.93

N1	ND	File Name	3_01	3_02	3_03	3_04	3_05	3_06	3_07	3_08	3_09	3_10	3_11	3_12	3_13	3_14	3_15	3_16
idle	idle	Pdata_20190130_1232_49	-3730	-294	159772	155042	175	257	387	274	446	19	-191	-139	-300	-264	-293	-188
40890	3600	Pdata_20190130_1234_59	-7220	-511	310212	300704	170	250	291	186	363	488	-267	-131	-135	-191	-478	-144
40890	4200	Pdata_20190130_1236_44	-7222	-519	311674	302018	175	249	404	233	604	266	-297	-111	-160	-198	-458	-157
40890	4200	Pdata_20190130_1237_08	-7236	-511	312853	303097	183	249	423	230	611	264	-302	-109	-164	-197	-462	-158
40890	4800	Pdata_20190130_1239_56	-7186	-486	311693	301951	186	247	466	314	774	145	-303	-84	-158	-205	-415	-174
40890	4800	Pdata_20190130_1241_24	-7140	-483	311068	301428	188	256	412	274	730	204	-299	-99	-154	-193	-429	-169
40890	4800	Pdata_20190130_1241_40	-7135	-488	310568	300938	190	270	424	278	730	209	-309	-106	-150	-190	-431	-159
40890	5400	Pdata_20190130_1243_21	-7150	-484	311543	301880	186	283	512	360	639	76	-268	-88	-185	-226	-386	-170
40890	5400	Pdata_20190130_1243_37	-7146	-486	311531	301957	184	280	512	356	614	80	-264	-88	-201	-224	-394	-174
40890	6000	Pdata_20190130_1244_56	-7139	-496	308565	299041	188	276	627	413	718	13	-262	-77	-260	-247	-374	-184
40890	6000	Pdata_20190130_1245_12	-7120	-492	308305	298853	184	270	637	428	715	20	-258	-83	-278	-252	-374	-189
46000	6000	Pdata_20190130_1246_56	-9369	-640	449062	436246	175	278	502	295	980	406	-462	-53	18	-140	-601	-146
46000	6000	Pdata_20190130_1247_12	-9352	-636	447638	434771	178	276	518	307	990	411	-454	-46	-75	-140	-607	-148
46000	5400	Pdata_20190130_1249_20	-9286	-634	447339	434509	178	270	560	290	761	528	-444	-57	-162	-167	-656	-146
46000	5400	Pdata_20190130_1249_36	-9295	-644	448229	435256	173	274	564	282	757	528	-452	-53	-49	-163	-658	-133
46000	5400	Pdata_20190130_1250_14	-9195	-636	444496	431627	169	272	548	280	794	498	-432	-64	-158	-159	-658	-140
46000	4800	Pdata_20190130_1252_43	-9102	-623	440413	427407	171	276	374	229	487	786	-385	-84	-89	-154	-634	-116
46000	4800	Pdata_20190130_1253_01	-9063	-625	438605	425683	171	270	378	227	487	769	-383	-86	-173	-152	-632	-119
46000	4200	Pdata_20190130_1255_31	-9155	-630	444075	431215	167	264	353	229	287	532	-375	-103	10	-116	-760	-100
46000	4200	Pdata_20190130_1255_47	-9132	-627	442889	429936	171	272	349	218	310	519	-368	-103	2	-118	-753	-102
46000	3600	Pdata_20190130_1256_50	-9259	-648	447034	434131	165	276	428	288	320	-326	-338	-114	-162	-165	-821	-85
46000	3600	Pdata_20190130_1257_05	-9197	-652	444219	431201	169	272	424	288	300	-268	-336	-114	-148	-157	-813	-83
51000	3600	Pdata_20190130_1259_02	-13338	-932	598110	582741	156	260	550	346	287	-979	-289	-108	-4	-82	-1655	-13
51000	3600	Pdata_20190130_1259_18	-13243	-930	597014	581886	152	266	562	371	291	-961	-289	-99	-37	-74	-1635	-11
51000	4200	Pdata_20190130_1300_28	-13018	-932	596776	581217	158	266	637	407	310	-1153	-377	-77	-2	-87	-1304	-27
51000	4200	Pdata_20190130_1300_46	-13013	-936	597843	582189	150	262	650	405	310	-1122	-387	-81	-199	-97	-1325	-30
51000	4800	Pdata_20190130_1301_59	-12941	-934	601856	585982	156	266	594	352	376	-820	-432	-73	-73	-53	-1928	-40
51000	4800	Pdata_20190130_1302_14	-12948	-938	601903	586220	147	264	585	348	383	-883	-430	-72	34	-55	-2070	-34
51000	5400	Pdata_20190130_1303_30	-12761	-940	601514	585936	141	262	475	265	270	22	-508	-59	118	-34	-1127	-44
51000	5400	Pdata_20190130_1303_46	-12778	-938	602101	586475	147	256	475	278	289	-105	-518	-50	134	-38	-1143	-44
51000	6000	Pdata_20190130_1304_37	-12788	-946	605965	590199	141	252	456	223	580	995	-561	-50	126	-34	-1024	-55
51000	6000	Pdata_20190130_1304_52	-12761	-940	604743	589037	151	260	454	220	601	1008	-563	-40	61	-46	-1036	-53
51000	6000	Pdata_20190130_1305_07	-12714	-938	603609	588158	162	254	447	208	603	1078	-559	-48	53	-47	-1026	-63

N1	ND	File Name	3_01	3_02	3_03	3_04	3_05	3_06	3_07	3_08	3_09	3_10	3_11	3_12	3_13	3_14	3_15	3_16
idle	idle	Pstd_20190130_1232_49	30.13	21.5	529.47	475.43	24.08	19.04	25.71	16.01	22.89	22.18	15.81	15.53	27.78	17.07	21.43	10.46
40890	3600	Pstd_20190130_1234_59	26.26	16.9	293.18	363.9	25.2	19.58	27.73	20.74	34.58	42.51	18.04	18.5	24.67	18.59	23.53	18.35
40890	4200	Pstd_20190130_1236_44	38.36	23.6	1287.57	1144.47	24.17	21.88	31.39	24.52	42.12	37.8	22.03	17.99	27.25	23.74	23.68	16.45
40890	4200	Pstd_20190130_1237_08	29.25	19.75	1022.85	916.67	21.65	19.35	29.32	22.08	49.28	38.6	20.37	11.74	20.91	23.14	18.65	17.47
40890	4800	Pstd_20190130_1239_56	32.22	23.62	438.72	446.13	20.88	22.79	33.55	39	70.59	65.74	24.98	17.26	36.16	25.81	22.16	19.04
40890	4800	Pstd_20190130_1241_24	24.22	26.48	248.64	280	8.31	29.24	17.04	27.11	34.17	28.2	22.97	20.97	21.77	20.95	19.8	22.91
40890	4800	Pstd_20190130_1241_40	20.79	19.86	458.62	454.85	11.44	29.44	19.57	30.75	49.17	18.13	21.61	11.3	20.62	17.4	17.35	15.55
40890	5400	Pstd_20190130_1243_21	30.72	19.86	657.92	636.15	20.88	28.44	25.72	19.44	52.13	22.41	26.24	18.45	22.51	19.36	19.8	23
40890	5400	Pstd_20190130_1243_37	25.94	23.62	523.73	442.14	18.97	27.01	28.57	22.61	82.41	21.76	28.02	18.45	28.3	20.95	18.99	22.67
40890	6000	Pstd_20190130_1244_56	18.5	17.29	462.02	404.25	18.97	11.97	18.76	16.93	41.97	21.76	18.39	11.3	32.35	28.86	18.99	18.54
40890	6000	Pstd_20190130_1245_12	22.19	19.04	603.73	642.07	8.31	19.82	19.27	17.8	31.8	28.12	23.4	20.2	29.92	18.56	22.78	12.29
46000	6000	Pstd_20190130_1246_56	22.19	19.86	815.82	919.67	17.47	26.05	48.02	26.35	63.08	38.91	24.08	18.74	29.95	24.91	26.7	22.25
46000	6000	Pstd_20190130_1247_12	22.61	22.85	785.48	867.48	15.25	17.37	36.27	16.93	71.9	31.58	19.66	16.31	33.59	21.66	18.99	16.94
46000	5400	Pstd_20190130_1249_20	28.17	18.3	771.38	741.29	15.25	23.49	26.1	28.21	61.07	57.5	19.14	18.74	69.91	19.06	11.94	18.54
46000	5400	Pstd_20190130_1249_36	24.22	19.86	769.09	776.43	18.19	8.69	25.19	28.74	41.97	59.96	19.96	22.2	35.88	24.91	23.46	23
46000	5400	Pstd_20190130_1250_14	20.8	19.04	620.77	645.21	18.97	17.82	30.73	22.65	56.45	65.27	15.41	20.2	46.1	23.35	29.45	21.64
46000	4800	Pstd_20190130_1252_43	26.3	0	941.55	948.12	18.68	11.95	24.49	14.92	53.43	45.94	14.33	17.26	33.53	14.94	18.99	8.47
46000	4800	Pstd_20190130_1253_01	29.72	19.86	775.77	853.26	22.23	15.3	31.16	21.28	57.65	31.53	16.05	17.97	50.18	12.3	18.24	13.88
46000	4200	Pstd_20190130_1255_31	31.51	15.97	527.94	611.19	22.55	29.82	26.68	22.9	23.3	67.24	26.62	19.21	31.01	19.36	26.4	18.54
46000	4200	Pstd_20190130_1255_47	25.72	11.98	752.17	728.7	18.68	12.6	17.15	20.83	26.44	82.43	19.66	15.07	23.85	20.95	29.25	17.81
46000	3600	Pstd_20190130_1256_50	61.9	19.04	2374.15	2282.62	18.97	21.46	25.72	22.65	35.57	129.69	22.97	23.52	25.25	25.44	22.78	24.2
46000	3600	Pstd_20190130_1257_05	37	17.29	788.08	748.83	18.97	17.82	15.11	19.03	32.11	71.94	19.66	11.3	44.06	22.27	29.45	19.82
51000	3600	Pstd_20190130_1259_02	37.35	15.33	1272.85	1306.9	19.44	18.26	18.76	13.87	29.24	89.46	19.66	14.47	71.1	22.27	36.21	18.54
51000	3600	Pstd_20190130_1259_18	41.18	17.4	1995.66	1987.09	11.44	19.01	18.76	23.31	42.34	107.07	19.66	17.26	246.56	28.79	42.27	21.64
51000	4200	Pstd_20190130_1300_28	68.72	19.86	2783.79	2778.87	20.44	14.23	19.27	16.82	36.38	103.51	19.14	11.3	88.14	21.66	26.4	17.81
51000	4200	Pstd_20190130_1300_46	61.16	8.7	2697.32	2578.74	14.64	17.26	15.11	17.8	31.8	82.43	12.04	15.07	53.45	19.36	31.53	15.55
51000	4800	Pstd_20190130_1301_59	25.36	21.87	1014.61	961.45	19.44	14.23	23.27	24.87	55.72	138.66	8.75	20.63	63	25.81	141.91	19.34
51000	4800	Pstd_20190130_1302_14	22.86	11.98	881.17	1026.36	18.97	15.94	21.09	15.54	42.34	105.58	21.98	14.47	57.64	19.36	64.52	11.66
51000	5400	Pstd_20190130_1303_30	37.6	14.26	948.91	958.79	15.25	17.25	19.27	12.28	43.29	173.07	28.38	24.98	55.79	16.96	29.45	13.88
51000	5400	Pstd_20190130_1303_46	22.86	11.98	954.33	1078.19	18.96	19.52	19.27	22.23	31.86	190.07	17.38	21.56	83.34	17.4	23.46	13.88
51000	6000	Pstd_20190130_1304_37	17.77	18.3	374.75	748.47	15.25	19.92	30.22	27.19	53.72	153.16	22.97	24.63	68.44	20.95	23.21	19.34
51000	6000	Pstd_20190130_1304_52	28.5	14.26	1035.87	1153.67	18.97	22.19	18.76	23.31	55.05	124.71	23.4	23.52	53.5	19.84	28.43	19.04
51000	6000	Pstd_20190130_1305_07	30.72	17.4	1166.21	999.29	27.68	23.49	31.16	26.06	72.09	162.6	31.34	17.26	36.82	27.17	38.75	22.25

N1	ND	File Name	1	2	3	4	5	6	7	8	9	10	11	12	13
40890	3600	Tdata_20190130_1234_59	290.89	290.66	473.75	475.99	830.57	736.11	741.02	740.42	2563.27	730.99	727.44	717.17	741.64
40890	4200	Tdata_20190130_1236_44	290.26	290.83	474.38	476.81	834.18	738.96	738.46	749.73	2563.34	726.79	724.03	711.92	745.16
40890	4200	Tdata_20190130_1237_08	289.86	290.94	474.45	477.02	833.94	739.76	738.97	749.91	2563.35	727.32	724.58	712.21	745.09
40890	4800	Tdata_20190130_1239_56	290.79	291.11	475.18	476.88	833.23	742.04	737.83	744.88	2563.47	729.68	726.47	711.56	738.91
40890	4800	Tdata_20190130_1241_24	290.04	291.13	474.04	477.12	833.74	740.98	736.57	745.75	2563.51	728.37	725.19	709.46	739.33
40890	4800	Tdata_20190130_1241_40	290.63	291.51	474.71	477.57	834.73	741.44	737.46	745.72	2563.52	728.94	725.61	709.83	739.52
40890	5400	Tdata_20190130_1243_21	291.54	291.44	475.80	477.85	833.25	743.02	740.41	746.50	2563.59	730.17	726.42	714.23	741.45
40890	5400	Tdata_20190130_1243_37	290.93	291.37	475.67	477.74	833.22	742.75	740.14	746.07	2563.59	729.71	725.95	713.79	741.07
40890	6000	Tdata_20190130_1244_56	289.98	291.16	473.55	476.39	823.05	864.55	739.45	743.91	2563.64	725.09	721.08	710.93	739.35
40890	6000	Tdata_20190130_1245_12	291.11	291.44	474.01	476.37	823.24	805.35	740.19	744.14	2563.66	725.70	721.59	711.42	739.65
46000	6000	Tdata_20190130_1246_56	290.96	290.10	526.17	525.93	903.29	793.60	769.91	776.39	2563.71	763.01	760.22	744.92	771.97
46000	6000	Tdata_20190130_1247_12	291.36	290.46	526.41	526.17	902.78	796.67	770.03	776.48	2563.73	762.93	760.09	745.17	771.94
46000	5400	Tdata_20190130_1249_20	290.97	290.36	525.95	525.86	902.25	1676.45	771.91	779.30	2563.79	759.65	757.36	745.28	777.51
46000	5400	Tdata_20190130_1249_36	290.69	290.56	525.45	525.66	901.58	2174.01	771.19	778.92	2563.81	759.28	756.94	744.89	777.12
46000	5400	Tdata_20190130_1250_14	291.44	290.72	525.91	526.00	902.05	2333.43	771.79	778.15	2563.83	759.78	757.65	745.72	776.26
46000	4800	Tdata_20190130_1252_43	291.71	291.20	525.57	525.93	899.05	2211.88	773.05	779.07	2563.90	761.90	759.90	750.33	779.31
46000	4800	Tdata_20190130_1253_01	292.06	291.34	524.99	524.76	898.04	2384.89	771.88	777.58	2563.90	760.12	758.11	748.72	777.60
46000	4200	Tdata_20190130_1255_31	292.16	291.17	526.19	526.36	892.68	1827.47	772.33	772.77	2563.96	764.47	762.33	751.14	772.41
46000	4200	Tdata_20190130_1255_47	292.23	291.56	526.89	527.07	893.11	2437.44	772.45	773.57	2563.97	764.49	761.73	751.10	772.89
46000	3600	Tdata_20190130_1256_50	291.46	290.95	526.76	527.62	888.93	2051.84	771.56	776.06	2564.00	767.66	1730.60	754.92	771.12
46000	3600	Tdata_20190130_1257_05	291.92	291.08	526.77	527.39	888.70	2276.71	771.14	776.95	2564.01	767.40	2563.74	754.77	772.08
51000	3600	Tdata_20190130_1259_02	292.17	291.25	574.42	576.13	1033.75	868.43	865.76	887.51	2564.05	870.27	865.76	855.97	878.45
51000	3600	Tdata_20190130_1259_18	292.40	291.04	575.08	576.50	1029.73	946.93	864.37	885.91	2564.06	868.90	865.12	855.78	877.24
51000	4200	Tdata_20190130_1300_28	292.38	292.41	575.80	578.58	1026.31	863.53	858.96	875.18	2564.09	855.80	851.83	842.39	869.66
51000	4200	Tdata_20190130_1300_46	292.32	292.06	575.23	578.15	1024.52	1004.70	857.55	873.96	2564.09	854.35	863.51	841.15	868.43
51000	4800	Tdata_20190130_1301_59	291.59	291.12	575.26	578.30	1032.13	1054.89	858.69	873.99	2564.13	850.60	1054.17	836.24	870.32
51000	4800	Tdata_20190130_1302_14	291.86	291.29	575.99	578.41	1032.59	1307.72	858.98	874.02	2564.14	850.48	1108.16	836.06	870.26
51000	5400	Tdata_20190130_1303_30	292.45	291.69	576.16	579.11	1039.51	1847.22	857.67	873.93	2564.18	847.66	1016.28	833.10	874.92
51000	5400	Tdata_20190130_1303_46	292.13	292.40	576.92	580.15	1041.23	1742.22	858.31	874.54	2564.18	848.21	1288.32	833.84	875.48
51000	6000	Tdata_20190130_1304_37	292.38	292.38	577.66	580.89	1049.03	1800.33	857.83	876.73	2564.19	846.18	892.45	832.57	879.03
51000	6000	Tdata_20190130_1304_52	292.06	292.03	576.76	580.46	1047.55	2055.37	855.93	877.44	2564.20	844.78	2026.36	831.11	879.81
51000	6000	Tdata_20190130_1305_07	292.56	292.50	576.82	580.20	1046.38	1591.63	854.55	877.96	2564.20	843.11	1115.51	829.64	880.33

N1	ND	File Name	1	2	3	4	5	6	7	8	9	10	11	12	13
40890	3600	Tstd_20190130_1234_59	0.24	0.17	0.19	0.17	0.58	0.12	0.12	0.36	0.01	0.08	0.12	0.09	0.41
40890	4200	Tstd_20190130_1236_44	0.12	0.08	0.21	0.20	0.75	0.28	0.25	0.29	0.01	0.18	0.14	0.20	0.20
40890	4200	Tstd_20190130_1237_08	0.07	0.03	0.49	0.32	0.92	0.22	0.22	0.32	0.01	0.24	0.22	0.09	0.26
40890	4800	Tstd_20190130_1239_56	0.36	0.08	0.47	0.31	1.20	0.08	0.23	0.62	0.01	0.09	0.09	0.65	0.26
40890	4800	Tstd_20190130_1241_24	0.16	0.07	0.10	0.10	0.63	0.24	0.33	0.16	0.01	0.20	0.16	0.18	0.11
40890	4800	Tstd_20190130_1241_40	0.21	0.16	0.19	0.21	0.98	0.21	0.20	0.23	0.01	0.16	0.20	0.19	0.22
40890	5400	Tstd_20190130_1243_21	0.18	0.05	0.34	0.27	0.78	0.19	0.21	0.18	0.00	0.12	0.11	0.22	0.11
40890	5400	Tstd_20190130_1243_37	0.31	0.04	0.26	0.11	0.49	0.36	0.27	0.19	0.00	0.30	0.24	0.18	0.17
40890	6000	Tstd_20190130_1244_56	0.28	0.01	0.21	0.26	0.69	209.96	0.07	0.15	0.01	0.13	0.11	0.13	0.07
40890	6000	Tstd_20190130_1245_12	0.19	0.07	0.12	0.18	0.40	86.69	0.12	0.20	0.01	0.10	0.08	0.07	0.20
46000	6000	Tstd_20190130_1246_56	0.03	0.04	0.33	0.24	0.87	20.47	0.22	0.10	0.01	0.12	0.14	0.18	0.14
46000	6000	Tstd_20190130_1247_12	0.05	0.07	0.43	0.31	1.05	19.39	0.39	0.24	0.01	0.16	0.14	0.23	0.19
46000	5400	Tstd_20190130_1249_20	0.04	0.05	0.35	0.24	0.69	463.87	0.46	0.22	0.01	0.16	0.15	0.17	0.17
46000	5400	Tstd_20190130_1249_36	0.06	0.06	0.18	0.13	0.63	545.11	0.39	0.14	0.01	0.19	0.17	0.25	0.16
46000	5400	Tstd_20190130_1250_14	0.05	0.05	0.21	0.25	0.43	427.37	0.19	0.14	0.01	0.07	0.09	0.10	0.13
46000	4800	Tstd_20190130_1252_43	0.06	0.07	0.20	0.16	0.97	565.45	0.18	0.24	0.01	0.21	0.16	0.15	0.37
46000	4800	Tstd_20190130_1253_01	0.13	0.05	0.26	0.24	0.76	436.90	0.39	0.37	0.00	0.18	0.19	0.19	0.27
46000	4200	Tstd_20190130_1255_31	0.08	0.07	0.32	0.20	0.30	893.16	0.45	0.15	0.01	0.29	1.92	0.24	0.24
46000	4200	Tstd_20190130_1255_47	0.06	0.05	0.19	0.21	0.36	308.60	0.16	0.43	0.01	0.12	0.92	0.12	0.46
46000	3600	Tstd_20190130_1256_50	0.07	0.05	0.51	0.46	1.23	700.03	0.22	0.18	0.01	0.18	393.06	0.14	0.24
46000	3600	Tstd_20190130_1257_05	0.14	0.10	0.32	0.26	0.59	598.75	0.46	0.29	0.01	0.07	0.01	0.09	0.21
51000	3600	Tstd_20190130_1259_02	0.08	0.24	0.45	0.36	1.55	18.57	0.26	0.27	0.01	0.10	0.19	0.22	0.14
51000	3600	Tstd_20190130_1259_18	0.06	0.04	0.17	0.14	1.03	101.32	0.28	0.50	0.01	0.26	0.15	0.16	0.52
51000	4200	Tstd_20190130_1300_28	0.16	0.04	0.67	0.80	1.99	14.52	0.54	0.27	0.01	0.43	0.47	0.36	0.33
51000	4200	Tstd_20190130_1300_46	0.15	0.10	0.43	0.50	1.66	224.28	0.36	0.32	0.01	0.22	14.23	0.19	0.29
51000	4800	Tstd_20190130_1301_59	0.08	0.14	0.24	0.28	0.70	393.00	0.62	0.29	0.01	0.29	154.16	0.28	0.35
51000	4800	Tstd_20190130_1302_14	0.08	0.22	0.31	0.38	0.73	428.99	0.49	0.17	0.01	0.36	138.89	0.27	0.21
51000	5400	Tstd_20190130_1303_30	0.03	0.09	0.41	0.35	1.58	590.53	0.67	0.09	0.01	0.44	217.30	0.34	0.24
51000	5400	Tstd_20190130_1303_46	0.12	0.03	0.18	0.17	0.45	555.42	0.54	0.42	0.01	0.23	555.41	0.32	0.50
51000	6000	Tstd_20190130_1304_37	0.04	0.10	0.31	0.31	0.94	700.93	0.59	1.08	0.01	0.37	71.19	0.30	1.14
51000	6000	Tstd_20190130_1304_52	0.05	0.05	0.25	0.19	0.89	420.84	0.46	0.40	0.01	0.27	707.59	0.30	0.31
51000	6000	Tstd_20190130_1305_07	0.09	0.11	0.26	0.17	0.92	595.81	0.59	0.42	0.01	0.47	222.17	0.35	0.49

B. 20190510: HEAT EXCHANGER CONFIGURATION

Atmospheric Pressure:	29.87 inHg																	
Timestamp	N1	ND	1_01	1_02	1_03	1_04	1_05	1_06	1_07	1_08	1_09	1_10	1_11	1_12	1_13	1_14	1_15	1_16
Pdata_20190510_112x2_11	idle	idle	-999999	-235	-12	-11	-11	-11	209	715	123	726	188	656	213	614	202	725
Pdata_20190510_1124_24	40890	3600	-999999	-447	-14	-11	-13	-13	1027	996	1253	1014	976	909	1096	931	1068	1076
Pdata_20190510_1125_14	40890	3600	-999999	-444	-11	-12	-12	-12	1019	982	1248	1023	964	895	1084	920	1053	1059
Pdata_20190510_1126_57	40890	4200	-999999	-445	-13	-13	-14	-12	1006	1026	954	1199	903	970	1009	1012	967	1163
Pdata_20190510_1129_17	40890	4800	-999999	-447	-14	-15	-14	-13	884	1168	720	1424	793	1120	896	1162	848	1319
Pdata_20190510_1134_50	40890	4800	-999999	-450	-11	-12	-13	-14	898	1167	735	1428	807	1121	915	1191	867	1321
Pdata_20190510_1137_10	40890	5400	-999999	-452	-17	-15	-14	-14	670	1585	555	1547	610	1476	680	1477	645	1613
Pdata_20190510_1137_29	40890	5400	-999999	-453	-15	-15	-15	-17	672	1590	547	1539	616	1482	683	1485	654	1619
Pdata_20190510_114x1_27	40890	5400	-999999	-449	-15	-16	-15	-15	659	1592	538	1541	599	1478	663	1494	630	1611
Pdata_20190510_114x2_42	40890	6000	-999999	-451	-16	-15	-15	-13	539	1792	325	1807	493	1649	557	1701	525	1822
Pdata_20190510_1145_23	40890	6000	-999999	-449	-16	-14	-17	-14	525	1787	316	1813	484	1647	545	1712	513	1817
Pdata_20190510_1145_43	40890	6000	-999999	-453	-15	-15	-14	-15	540	1797	326	1819	491	1653	553	1720	521	1827
Pdata_20190510_1150_31	46000	6000	-999999	-591	-15	-15	-15	-15	1579	1786	1384	2165	1444	1738	1639	1980	1549	2078
Pdata_20190510_115x1_43	46000	6000	-999999	-594	-15	-15	-14	-14	1580	1800	1398	2186	1440	1751	1630	1988	1542	2085
Pdata_20190510_1156_14	46000	5400	-999999	-586	-15	-15	-15	-14	1719	1587	1682	1917	1544	1537	1725	1792	1659	1858
Pdata_20190510_1156_42	46000	5400	-999999	-586	-15	-13	-14	-16	1715	1591	1677	1904	1540	1537	1721	1794	1653	1857
Pdata_20190510_1200_09	46000	4800	-999999	-588	-14	-14	-14	-15	1633	1652	2008	1714	1547	1518	1746	1748	1695	1798
Pdata_20190510_120x1_39	46000	4200	-999999	-588	-14	-13	-14	-15	1776	1556	2320	1532	1720	1405	1946	1605	1898	1614
Pdata_20190510_120x2_43	46000	3600	-999999	-594	-15	-14	-14	-14	1859	1490	1737	1310	1865	1334	2114	1503	2073	1501
Pdata_20190510_120x3_59	51000	3600	-999999	-839	-19	-19	-18	-19	135668	2344	2046	1956	999999	2117	999999	2242	999999	2287
Pdata_20190510_1205_24	51000	4200	-999999	-841.5	-15.55	-14.45	-16	-16.14	999999	2312.9	2018.8	2027.45	999999	2056.73	999999	2272.3	999999	2282.73
Pdata_20190510_1206_14	51000	4800	-999999	-840	-15	-15	-16	-16	999999	2332	69015	2025	999999	2093	999999	2373	999999	2362
Pdata_20190510_1206_39	51000	4800	-999999	-841	-16	-14	-17	-16	999999	2336	102211	2077	999999	2095	999999	2384	999999	2368
Pdata_20190510_1207_23	51000	5400	-999999	-828	-17	-17	-17	-17	168938	2396	999999	2359	2649	2160	999999	2510	999999	2501
Pdata_20190510_1210_16	idle	idle	-202182	-231	-12	-12	-14	-13	187	699	105	699	171	646	193	695	-2019	707

Timestamp	N1	ND	1_01	1_02	1_03	1_04	1_05	1_06	1_07	1_08	1_09	1_10	1_11	1_12	1_13	1_14	1_15	1_16
Pstd_20190510_1122_11	idle	idle	0	2.41	2.35	2.39	2.62	1.89	5.34	5.04	9.56	15.15	2.92	4.45	2.73	4.75	2.47	4.98
Pstd_20190510_1124_24	40890	3600	0	1.96	3.47	3.46	3.65	4.02	20.28	21.85	33.76	30.94	14.18	16.44	16.19	13.41	14.19	16.7
Pstd_20190510_1125_14	40890	3600	0	2.88	5.22	3.69	4.51	4.77	19.46	20.79	22.19	28.6	12.62	14.94	14.56	10.91	13.9	11.88
Pstd_20190510_1126_57	40890	4200	0	2.21	5.35	5.07	4.24	3.98	17.88	22.49	20.47	39.92	12.33	16.59	14.06	11.81	12.56	13.12
Pstd_20190510_1129_17	40890	4800	0	1.93	3.67	4.96	4.66	4.61	13.97	16.27	20.54	42.47	11.28	13.18	14.4	10.38	11.66	14.15
Pstd_20190510_1134_50	40890	4800	0	2.88	3.29	4.46	3.24	4.65	12.09	20.92	17.3	41.98	11.23	14.7	15.58	13.82	15.14	15.3
Pstd_20190510_1137_10	40890	5400	0	1.84	4.74	4.56	5.19	6.2	16.69	29.39	29.48	53.73	13.9	20.68	19.8	25.02	17.05	25.08
Pstd_20190510_1137_29	40890	5400	0	2.47	4.84	4.39	4.15	4.83	17.18	28.52	24.3	76.41	14.48	24.67	17.3	23.88	15.61	27.09
Pstd_20190510_1141_27	40890	5400	0	2.22	3.54	5.64	5.44	5.54	18.45	27.79	23.45	55.96	18.28	27.68	22.02	26.2	23.64	27.74
Pstd_20190510_1142_42	40890	6000	0	2.31	5.21	4.29	5.59	5.7	9.49	8.23	21.2	37.53	9.21	6.45	12.21	7.7	12.32	9.35
Pstd_20190510_1145_23	40890	6000	0	2.1	5.25	5.55	5.02	5.31	11.5	8.87	21.26	28.42	7.01	8.31	9.38	8.35	12.34	10.9
Pstd_20190510_1145_43	40890	6000	0	2.29	6.42	5.56	6.04	5.01	10.29	8.4	16.89	22.74	7.07	8.29	8.35	11.23	8.68	11.45
Pstd_20190510_1150_31	46000	6000	0	2.38	4.33	3.74	4.04	4.18	18.86	25.91	30.7	59.51	13.09	19.22	16.77	19.22	14.18	17.06
Pstd_20190510_1151_43	46000	6000	0	3.32	4.18	4.67	4.25	5.33	21.65	20.69	37.51	48.22	18.02	18.43	18.31	15.33	15.47	14.91
Pstd_20190510_1156_14	46000	5400	0	2.8	4.51	4.09	3.87	3.86	20.64	30.12	36.38	40.13	14.88	26.03	18.07	20.49	14.72	22.23
Pstd_20190510_1156_42	46000	5400	0	2.76	4.8	4.5	3.79	3.94	26.37	27.9	30.24	47.1	19.39	22.14	22.13	19.57	19.7	19.91
Pstd_20190510_1200_09	46000	4800	0	3.09	4.4	3.91	4.09	3.85	18.16	22.03	46.92	48.72	14.53	16.83	15.65	15.99	14.69	13.74
Pstd_20190510_1201_39	46000	4200	0	2.53	4	3.92	3.74	3.38	20.85	18.12	69.97	35.71	13.02	15.93	14.84	13.66	11.82	12.86
Pstd_20190510_1202_43	46000	3600	0	3	4.15	3.79	4.1	4.24	19.27	13.81	102.72	37.36	11.88	13.56	12.91	13.19	10.59	12.69
Pstd_20190510_1203_59	51000	3600	0	3.77	7.56	5.63	6.31	5.76	3E+05	36.92	146.61	69.01	0	39.35	0	36.7	0	35.86
Pstd_20190510_1205_24	51000	4200	0	3.52	4.53	5.41	5.73	4.81	0	14.22	126.53	44.06	0	16.33	0	18.85	0	12.56
Pstd_20190510_1206_14	51000	4800	0	4.24	6.57	6.54	6.21	6.97	0	21.64	3E+05	48	0	19.84	0	20.35	0	17.85
Pstd_20190510_1206_39	51000	4800	0	2.78	6.58	6.23	4.63	5.02	0	17.69	3E+05	40.4	0	17.13	0	19.45	0	16.59
Pstd_20190510_1207_23	51000	5400	0	3.4	5.95	6.91	5.66	7.35	4E+05	21.86	0	52.08	19.83	22.42	0	20.16	0	20.58

Timestamp	N1	ND	2_01	2_02	2_03	2_04	2_05	2_06	2_07	2_08	2_09	2_10	2_11	2_12	2_13	2_14	2_15	2_16
Pdata_20190510_112x2_11	idle	idle	-2864	-238	-11	-14	-12	-13	210	715	122	724	187	654	213	613	200	725
Pdata_20190510_1124_24	40890	3600	-5866	-449	-14	-14	-13	-14	1028	995	1253	1018	976	909	1095	928	1067	1075
Pdata_20190510_1125_14	40890	3600	-5778	-447	-13	-16	-13	-14	1020	981	1245	1024	964	894	1083	917	1052	1058
Pdata_20190510_1126_57	40890	4200	-5766	-448	-13	-16	-13	-13	1007	1025	955	1197	902	970	1008	1010	965	1162
Pdata_20190510_1129_17	40890	4800	-5788	-450	-15	-16	-13	-13	886	1167	720	1426	793	1116	895	1160	847	1318
Pdata_20190510_1134_50	40890	4800	-5791	-454	-12	-15	-13	-15	899	1165	736	1427	806	1118	915	1189	867	1320
Pdata_20190510_1137_10	40890	5400	-5773	-454	-15	-18	-16	-17	672	1584	555	1552	610	1474	680	1474	644	1613
Pdata_20190510_1137_29	40890	5400	-5791	-456	-14	-18	-17	-17	674	1589	548	1541	616	1479	683	1481	654	1618
Pdata_20190510_114x1_27	40890	5400	-5713	-453	-18	-19	-16	-17	660	1590	537	1535	600	1475	664	1491	629	1610
Pdata_20190510_114x2_42	40890	6000	-5754	-454	-15	-15	-14	-16	541	1791	324	1802	493	1647	557	1697	524	1822
Pdata_20190510_1145_23	40890	6000	-5703	-452	-14	-15	-16	-15	526	1786	314	1814	484	1644	546	1709	513	1817
Pdata_20190510_1145_43	40890	6000	-5752	-456	-15	-17	-15	-16	542	1796	326	1815	492	1651	554	1717	520	1826
Pdata_20190510_1150_31	46000	6000	-7655	-594	-14	-16	-14	-15	1580	1786	1386	2158	1444	1736	1639	1977	1548	2079
Pdata_20190510_115x1_43	46000	6000	-7670	-597	-14	-15	-16	-16	1582	1799	1397	2188	1440	1749	1629	1986	1541	2087
Pdata_20190510_1156_14	46000	5400	-7545	-589	-14	-16	-13	-14	1722	1587	1683	1919	1544	1534	1724	1789	1658	1860
Pdata_20190510_1156_42	46000	5400	-7539	-588	-12	-15	-14	-16	1717	1591	1679	1904	1541	1535	1720	1791	1652	1859
Pdata_20190510_1200_09	46000	4800	-7529	-589	-13	-15	-13	-14	1637	1652	2011	1719	1548	1516	1746	1746	1695	1801
Pdata_20190510_120x1_39	46000	4200	-7560	-590	-11	-15	-13	-13	1779	1558	2324	1532	1720	1404	1946	1603	1898	1617
Pdata_20190510_120x2_43	46000	3600	-7613	-595	-11	-14	-13	-14	1863	1491	1735	1311	1866	1334	2114	1502	2074	1504
Pdata_20190510_120x3_59	51000	3600	-10639	-838	-14	-18	-16	-17	2715	2346	2055	1962	2980	2117	3388	2241	3609	2291
Pdata_20190510_1205_24	51000	4200	-10383.13	-840.84	-9.93	-15.39	-14.29	-14.11	2929.64	2314.6	2023.75	2029.24	2964.34	2056.32	3362.6	2270.69	4106.49	2286.97
Pdata_20190510_1206_14	51000	4800	-10276	-839	-11	-16	-13	-15	2910	2333	2543	2034	2862	2093	3240	2372	3354	2366
Pdata_20190510_1206_39	51000	4800	-10278	-840	-11	-16	-14	-14	2922	2338	2500	2074	2873	2096	3246	2383	3565	2372
Pdata_20190510_1207_23	51000	5400	-10088	-827	-12	-16	-14	-13	2739	2399	3204	2363	2650	2160	2995	2509	4037	2505
Pdata_20190510_1210_16	idle	idle	-2771	-230	-9	-12	-9	-10	193	702	108	701	174	643	196	695	-2020	713

Timestamp	N1	ND	2_01	2_02	2_03	2_04	2_05	2_06	2_07	2_08	2_09	2_10	2_11	2_12	2_13	2_14	2_15	2_16
Pstd_20190510_1122_11	idle	idle	5.98	2.12	2.38	1.48	1.9	1.88	5.4	4.94	9.32	14.24	2.78	4.43	2.86	5.02	2.33	4.93
Pstd_20190510_1124_24	40890	3600	12.38	2.22	4.27	4.4	3.44	2.98	20.4	22.12	32.7	27.25	14.05	16.53	16.06	13.28	13.74	16.4
Pstd_20190510_1125_14	40890	3600	11.01	2.92	4.07	3.92	3.73	3.7	19.35	20.77	23.23	27.57	12.5	14.87	13.92	11.07	13.96	12.12
Pstd_20190510_1126_57	40890	4200	11.55	2.43	4.07	4	3.15	4.51	18.26	22.32	20.62	39.82	12.4	16.45	14.08	12.11	12.5	13.43
Pstd_20190510_1129_17	40890	4800	7.12	2.13	4.82	3.82	3.09	3.29	13.6	16.11	19.17	34.74	11.6	13.36	14.17	10.1	11.79	14.19
Pstd_20190510_1134_50	40890	4800	18.96	2.72	4.71	3.16	3.06	3.49	12.47	20.57	14.15	34.34	11.2	14.63	15.75	13.63	15.16	15.14
Pstd_20190510_1137_10	40890	5400	10.6	1.6	5.11	3.69	3.96	4.14	16.55	29.14	28.42	49.25	14.22	20.63	19.82	25.3	17.06	24.85
Pstd_20190510_1137_29	40890	5400	30.44	2.29	4.92	3.21	2.98	3.85	17.27	28.31	22.89	77.3	14.5	24.85	17.23	24.01	15.43	27.25
Pstd_20190510_1141_27	40890	5400	9.39	2.61	4.33	3.83	4.15	3.51	18.6	27.6	23.78	52.24	18.19	27.84	21.96	25.96	23.62	27.81
Pstd_20190510_1142_42	40890	6000	12.61	2.5	6.74	5.62	5.35	3.78	9.31	8.39	19.75	34.47	9.31	6.44	12.07	7.74	12.22	9.12
Pstd_20190510_1145_23	40890	6000	17.17	2.32	4.77	4.31	4.57	4.96	11.53	9.01	19.61	33.63	7.18	7.67	9.43	8.14	12.23	11.23
Pstd_20190510_1145_43	40890	6000	11.06	1.97	5.13	4.96	4.22	5.09	10.31	8.36	16.4	25.78	7.36	8.24	8.4	11.28	8.6	11.42
Pstd_20190510_1150_31	46000	6000	10.69	2.32	4.27	4.69	5.18	3.36	19.14	25.96	29.53	62.38	13.36	18.92	16.96	18.96	14.11	17.26
Pstd_20190510_1151_43	46000	6000	20.47	3.3	4.23	5.03	4.38	3.92	21.81	20.7	34.65	46.95	18.21	18.42	18.58	15.25	15.18	15.21
Pstd_20190510_1156_14	46000	5400	23.7	3.21	4.65	3.68	3.88	5.41	20.88	29.9	33.05	47.1	14.76	26	17.94	20.91	14.64	22
Pstd_20190510_1156_42	46000	5400	23.83	3.47	5.6	4.34	3.62	3.7	26.49	27.92	28.53	46.6	19.29	21.65	21.98	19.5	19.65	20.06
Pstd_20190510_1200_09	46000	4800	16.44	2.88	5.04	3.67	4.03	4.45	18.09	21.88	45.92	50.26	14.47	16.41	16	16.05	14.71	13.82
Pstd_20190510_1201_39	46000	4200	14.66	3.02	4.05	4.72	4.18	4.19	20.71	18.12	73.98	32.1	12.94	15.52	14.97	13.22	11.75	12.93
Pstd_20190510_1202_43	46000	3600	19.47	2.91	5.61	3.91	4.87	4.77	19.15	13.85	94.64	37.17	12.13	13.64	13.02	13.14	10.89	12.57
Pstd_20190510_1203_59	51000	3600	26.17	3.71	7.13	5.05	7.42	6.18	62.75	36.52	153.34	68.12	38.27	39.61	54.54	36.88	365.64	35.8
Pstd_20190510_1205_24	51000	4200	38.74	3.93	4.51	5.21	4.51	5.11	26.03	14.11	120.6	42.11	17.2	15.92	16.04	18.88	837.84	12.63
Pstd_20190510_1206_14	51000	4800	24.51	4.05	5.23	6.71	6.2	5.5	22.02	21.65	133.54	50.73	18.83	19.33	19.84	20.5	303.47	17.97
Pstd_20190510_1206_39	51000	4800	18.64	3.36	4.87	4.93	5.19	4.89	23.74	17.59	158.43	39.18	17.35	16.92	15.8	19.61	176.98	16.24
Pstd_20190510_1207_23	51000	5400	27.06	3.41	4.85	6.5	4.75	4.38	24.35	22.28	115.58	45.46	19.72	21.83	23.69	20.13	312.11	20.33

Timestamp	N1	ND	3_01	3_02	3_03	3_04	3_05	3_06	3_07	3_08	3_09	3_10	3_11	3_12	3_13	3_14	3_15	3_16
Pdata_20190510_112x2_11	idle	idle	-2885	-263	153482	148868	-39	-35	192	683	98	719	155	654	201	622	200	715
Pdata_20190510_1124_24	40890	3600	-5885	-467	299920	291194	-41	-33	1022	967	1246	1006	952	905	1089	934	1083	1075
Pdata_20190510_1125_14	40890	3600	-5797	-469	297049	288627	-45	-39	1014	954	1237	1002	934	890	1077	920	1063	1058
Pdata_20190510_1126_57	40890	4200	-5789	-459	298726	290069	-43	-39	995	996	936	1175	875	971	1024	1010	980	1158
Pdata_20190510_1129_17	40890	4800	-5790	-469	299619	290875	-48	-39	868	1164	699	1406	760	1113	892	1167	856	1327
Pdata_20190510_1134_50	40890	4800	-5793	-469	301397	292575	-32	-45	876	1166	695	1386	770	1116	919	1190	867	1331
Pdata_20190510_1137_10	40890	5400	-5778	-483	299566	290743	-39	-45	644	1593	522	1510	564	1463	681	1482	644	1623
Pdata_20190510_1137_29	40890	5400	-5802	-479	300422	291730	-35	-52	646	1595	508	1495	574	1467	696	1490	652	1628
Pdata_20190510_114x1_27	40890	5400	-5724	-473	297814	289097	-58	-60	627	1593	497	1477	558	1456	669	1488	629	1623
Pdata_20190510_114x2_42	40890	6000	-5763	-483	297144	288444	-56	-49	527	1794	316	1749	439	1636	560	1719	520	1821
Pdata_20190510_1145_23	40890	6000	-5721	-481	295449	286851	-63	-58	518	1785	299	1793	427	1638	544	1744	506	1791
Pdata_20190510_1145_43	40890	6000	-5773	-473	297641	289004	-62	-65	534	1791	312	1787	451	1639	568	1755	510	1797
Pdata_20190510_1150_31	46000	6000	-7680	-629	426496	414313	-51	-60	1584	1779	1384	2128	1405	1718	1652	2004	1550	2052
Pdata_20190510_115x1_43	46000	6000	-7701	-628	426638	414546	-37	-62	1584	1788	1400	2150	1404	1729	1654	2015	1534	2066
Pdata_20190510_1156_14	46000	5400	-7561	-623	419105	407172	-46	-69	1722	1591	1674	1875	1496	1511	1742	1813	1652	1840
Pdata_20190510_1156_42	46000	5400	-7553	-627	418726	406742	-46	-71	1713	1606	1672	1854	1491	1511	1730	1814	1645	1840
Pdata_20190510_1200_09	46000	4800	-7540	-627	418069	406064	-67	-75	1628	1682	1998	1667	1500	1496	1762	1763	1695	1779
Pdata_20190510_120x1_39	46000	4200	-7571	-634	417092	405100	-71	-69	1776	1579	2316	1477	1669	1381	1949	1629	1891	1602
Pdata_20190510_120x2_43	46000	3600	-7632	-643	419498	407376	-66	-66	1848	1510	1713	1278	1811	1313	2112	1553	2068	1491
Pdata_20190510_120x3_59	51000	3600	-10655	-879	557342	544077	-53	-76	2694	2356	2034	1937	2926	2083	3390	2270	3566	2248
Pdata_20190510_1205_24	51000	4200	-10402.71	-885.94	556232.7	542907.09	-38.38	-73.71	2908.79	2323.67	1999.09	1993.53	2904.05	2025.44	3362.04	2305.34	4063.21	2245.6
Pdata_20190510_1206_14	51000	4800	-10299	-881	556571	543197	-35	-80	2883	2343	2515	2000	2807	2063	3252	2404	3314	2332
Pdata_20190510_1206_39	51000	4800	-10303	-889	556947	543694	-36	-76	2902	2350	2472	2032	2809	2066	3261	2412	3526	2333
Pdata_20190510_1207_23	51000	5400	-10114	-872	552291	539080	-45	-80	2708	2407	3175	2322	2589	2127	3000	2549	3991	2462
Pdata_20190510_1210_16	idle	idle	-2801	-276	148425	144073	-54	-79	158	688	69	658	98	622	197	722	-2032	693

Timestamp	N1	ND	3_01	3_02	3_03	3_04	3_05	3_06	3_07	3_08	3_09	3_10	3_11	3_12	3_13	3_14	3_15	3_16
Pstd_20190510_1122_11	idle	idle	18.49	17.29	138.62	154.41	14.63	17.36	12.44	14.92	19.66	22.17	19.99	15.07	17.65	19.08	14.22	13.89
Pstd_20190510_1124_24	40890	3600	20.79	0	374.97	442.06	16.61	14.22	25.72	25.98	31.31	24.86	18.41	24.63	23.61	19.08	24.87	22.26
Pstd_20190510_1125_14	40890	3600	18.99	15.33	252.88	306.94	15.24	0	19.57	26.35	35.13	30.59	22.99	16.31	18.52	24.24	23.22	24.29
Pstd_20190510_1126_57	40890	4200	19.54	20.36	374.44	432.34	13.61	12.59	23.19	27.74	28.22	46.72	22.99	25.2	20.07	19.08	21.35	19.35
Pstd_20190510_1129_17	40890	4800	19.05	19.86	332.98	384.54	17.46	0	22.51	29.64	18.85	40.73	26.65	20.98	19.83	16.86	15.29	21.3
Pstd_20190510_1134_50	40890	4800	20.79	8.7	911.89	944.81	13.61	14.22	14.05	29.06	23.3	42.34	19.16	21.97	22.54	18.57	18.99	20.95
Pstd_20190510_1137_10	40890	5400	22.19	19.56	392.44	414.97	14.63	14.22	23.6	32.25	26.44	50.83	23.43	24.63	28.19	31.33	26.41	29.11
Pstd_20190510_1137_29	40890	5400	28.76	22.23	1515.25	1457.95	14.64	18.99	25.72	30.76	23.71	82.66	22.99	27.87	23.16	27.19	15.93	31.3
Pstd_20190510_1141_27	40890	5400	19.37	19.04	306.91	342.83	18.95	19.81	25.72	34.51	32.79	58	30.8	27.36	34.93	33.95	27.01	33.99
Pstd_20190510_1142_42	40890	6000	23.13	19.56	437.63	513.03	19.04	17.24	32.53	19.02	32.08	37.17	16.07	18.74	24.28	21.46	19.51	28.67
Pstd_20190510_1145_23	40890	6000	28.49	19.04	877.34	693.88	21.21	19.91	19.67	18.53	27.59	32.7	25.1	18.45	35.2	14.95	19.81	20.86
Pstd_20190510_1145_43	40890	6000	21.48	14.75	547.98	511.47	17.8	18.61	17.25	17.65	23.4	28.68	19.92	18	30.31	16.33	16.85	18.89
Pstd_20190510_1150_31	46000	6000	16.26	14.75	789.78	730.57	24.82	19.69	24.97	29.83	30.23	64.32	22.38	20.22	35.29	25.21	22.64	23.84
Pstd_20190510_1151_43	46000	6000	27	19.75	1298.78	1235.13	13.79	19.34	28.74	21.52	39.61	47.16	20.79	22.3	29.18	20.79	24.4	21.7
Pstd_20190510_1156_14	46000	5400	36.36	14.45	1171.16	1121.16	15.97	16.69	23.29	37.75	29.9	51.12	21.58	32.1	25.51	29.37	26.35	25.83
Pstd_20190510_1156_42	46000	5400	30.91	15.67	1157.29	1134.94	18.71	17.9	32.37	30.88	34.45	46.14	30.75	27.41	24.8	25.21	26.18	25.84
Pstd_20190510_1200_09	46000	4800	21.6	15.67	622.17	671.96	17.98	14.17	21.91	30.93	51.31	53.3	20.96	27.16	21.56	21.68	18.61	19.75
Pstd_20190510_1201_39	46000	4200	21.16	23.19	857.36	921.68	14.95	16.69	30.76	19.71	75.52	34.72	19.52	26.58	22.15	32.74	20.21	17.05
Pstd_20190510_1202_43	46000	3600	27.15	22.23	1454.63	1525.69	15.97	20.75	27.39	20.73	95.28	44.33	22.26	22.99	19.88	19.76	23.13	20.73
Pstd_20190510_1203_59	51000	3600	37.76	21.92	965.4	1149.36	23.24	21.57	65.2	42.09	150.17	72.78	46.18	45.16	37.25	45.75	363.82	41.23
Pstd_20190510_1205_24	51000	4200	38.62	19.61	1170.25	1110.35	11.88	15.62	29.75	18.86	118.55	43.95	26.69	21.74	22.48	27.62	834.84	16.31
Pstd_20190510_1206_14	51000	4800	27.51	26.02	664.23	871.67	16.7	14.17	27.39	25.04	136.14	56.31	29.7	26.23	31.89	29.02	298.46	27.72
Pstd_20190510_1206_39	51000	4800	22.92	17.94	882.2	852.36	11.87	12.41	26.92	22.99	156.08	44.68	23.35	21.42	27.73	25.76	179.94	21.66
Pstd_20190510_1207_23	51000	5400	33.41	21.92	890.31	932.91	15.1	9.84	23.58	25.53	117.83	44.94	25.92	25.39	32.65	33.64	312.31	26.22

Timestamp	N1	ND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tdata_20190510_1122_11	idle	idle	292.94	293.27	407.09	407.14	802.52	756.59	753.33	739.34	746.76	738.36	2566.23	2566.23	733.83	2566.23	2566.23
Tdata_20190510_1124_24	40890	3600	296.11	296.17	479.41	479.41	848.16	1040.24	759.53	761.46	757.70	747.23	2566.27	2566.27	761.00	2566.27	2566.27
Tdata_20190510_1125_14	40890	3600	297.21	297.53	480.34	480.48	849.19	952.20	761.16	764.51	760.64	748.77	2566.27	2566.27	763.93	2566.27	2566.27
Tdata_20190510_1126_57	40890	4200	297.43	297.90	481.28	481.22	853.09	779.91	757.84	767.40	764.71	748.64	2566.31	2566.31	765.12	2566.31	2566.31
Tdata_20190510_1129_17	40890	4800	298.60	298.07	482.15	481.30	853.12	794.71	756.32	767.91	767.58	748.68	2566.36	2566.36	761.49	2566.36	2566.36
Tdata_20190510_1134_50	40890	4800	298.52	298.59	483.89	483.95	855.41	1085.92	757.63	769.97	769.14	749.81	2566.48	2566.48	763.74	2566.48	2566.48
Tdata_20190510_1137_10	40890	5400	298.80	298.12	482.85	482.02	851.25	1124.14	762.19	767.26	770.96	752.11	2566.52	2566.52	761.74	2566.52	2566.52
Tdata_20190510_1137_29	40890	5400	298.98	298.12	482.84	481.88	850.36	2034.38	762.74	766.01	769.87	752.78	2566.54	2566.54	760.62	2566.54	2566.54
Tdata_20190510_1141_27	40890	5400	300.34	299.24	483.64	482.46	853.15	1499.48	764.82	768.84	772.36	754.47	2566.62	2566.62	762.97	2566.62	2566.62
Tdata_20190510_1142_42	40890	6000	299.87	298.78	482.90	481.76	842.97	1219.13	763.35	764.33	767.67	751.54	2566.65	2566.65	758.97	2566.65	2566.65
Tdata_20190510_1145_23	40890	6000	300.48	299.57	483.34	482.26	844.68	1539.90	764.68	766.25	769.69	752.83	2566.70	2566.70	760.82	2566.70	2566.70
Tdata_20190510_1145_43	40890	6000	300.08	299.17	483.55	482.61	844.66	1736.24	764.75	765.51	768.81	752.96	2566.71	2566.71	760.11	2566.71	2566.71
Tdata_20190510_1150_31	46000	6000	300.86	300.45	535.87	535.18	927.12	1292.99	793.03	803.91	803.49	787.47	2566.76	2566.76	799.74	2566.76	2566.76
Tdata_20190510_1151_43	46000	6000	301.80	300.86	538.05	536.53	928.20	892.63	794.26	808.05	807.72	789.17	2566.78	2566.78	804.00	2566.78	2566.78
Tdata_20190510_1156_14	46000	5400	303.25	301.43	536.80	535.33	928.08	1554.92	796.52	811.51	810.33	788.33	2566.84	2566.84	808.86	2566.84	2566.84
Tdata_20190510_1156_42	46000	5400	303.06	301.87	536.81	535.46	928.30	1873.66	797.29	811.01	809.81	788.83	2566.85	2566.85	808.79	2566.85	2566.85
Tdata_20190510_1200_09	46000	4800	302.94	301.80	536.71	535.25	926.96	1114.94	801.15	811.40	808.32	789.14	2566.91	2566.91	810.04	2566.91	2566.91
Tdata_20190510_1201_39	46000	4200	303.56	302.27	537.05	535.21	921.29	2461.92	803.13	806.97	803.53	792.91	2566.93	2566.93	805.70	2566.93	2566.93
Tdata_20190510_1202_43	46000	3600	303.15	302.42	537.95	537.19	916.69	2566.92	801.69	808.23	804.90	796.17	2566.94	2566.94	803.83	2566.94	2566.94
Tdata_20190510_1203_59	51000	3600	307.27	305.19	589.56	587.79	1051.56	903.65	886.68	905.57	910.52	887.56	2566.96	2566.96	902.72	2566.96	2566.96
Tdata_20190510_1205_24	51000	4200	309.22	306.40	593.79	591.42	1045.66	920.30	887.48	900.67	899.66	881.32	2566.98	2566.98	894.89	2566.98	2566.98
Tdata_20190510_1206_14	51000	4800	309.60	307.28	594.94	592.07	1053.60	920.48	888.94	902.42	898.63	877.84	2566.99	2566.99	899.61	2566.99	2566.99
Tdata_20190510_1206_39	51000	4800	309.93	307.78	594.47	591.71	1052.12	901.97	890.33	900.01	896.31	878.78	2566.99	2566.99	897.12	2566.99	2566.99
Tdata_20190510_1207_23	51000	5400	310.24	308.06	593.24	590.69	1054.61	925.53	887.17	895.84	892.47	874.47	2567.00	2567.00	895.74	2567.00	2567.00
Tdata_20190510_1210_16	idle	idle	299.84	298.74	412.85	412.85	799.82	935.70	754.39	740.36	747.34	738.96	2567.03	2567.03	734.52	2567.03	2567.03

Timestamp	N1	ND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tstd_20190510_1122_11	idle	idle	0.05	0.02	0.07	0.05	0.54	9.85	0.46	0.26	0.33	0.37	0.01	0.01	0.26	0.01	0.01
Tstd_20190510_1124_24	40890	3600	0.26	0.09	0.15	0.14	0.28	284.30	0.17	0.82	0.76	0.14	0.01	0.01	0.59	0.01	0.01
Tstd_20190510_1125_14	40890	3600	0.13	0.04	0.09	0.31	0.46	94.13	0.39	0.24	0.19	0.17	0.01	0.01	0.30	0.01	0.01
Tstd_20190510_1126_57	40890	4200	0.05	0.08	0.21	0.26	0.58	12.63	0.40	0.21	0.19	0.31	0.01	0.01	0.17	0.01	0.01
Tstd_20190510_1129_17	40890	4800	0.08	0.04	0.11	0.09	0.88	41.21	0.35	0.45	0.30	0.20	0.01	0.01	0.40	0.01	0.01
Tstd_20190510_1134_50	40890	4800	0.12	0.03	0.34	0.38	1.12	611.69	0.19	0.17	0.22	0.16	0.01	0.01	0.21	0.01	0.01
Tstd_20190510_1137_10	40890	5400	0.12	0.02	0.07	0.10	0.56	172.24	0.24	0.17	0.14	0.19	0.01	0.01	0.13	0.01	0.01
Tstd_20190510_1137_29	40890	5400	0.05	0.03	0.28	0.42	1.48	524.23	0.19	0.38	0.28	0.10	0.01	0.01	0.38	0.01	0.01
Tstd_20190510_1141_27	40890	5400	0.06	0.06	0.08	0.11	0.49	323.00	0.14	0.16	0.16	0.12	0.01	0.01	0.10	0.01	0.01
Tstd_20190510_1142_42	40890	6000	0.10	0.04	0.28	0.30	0.39	557.06	0.18	0.09	0.15	0.11	0.01	0.01	0.07	0.01	0.01
Tstd_20190510_1145_23	40890	6000	0.06	0.02	0.11	0.27	0.94	586.01	0.29	0.16	0.15	0.22	0.01	0.01	0.12	0.01	0.01
Tstd_20190510_1145_43	40890	6000	0.08	0.02	0.19	0.17	0.49	559.46	0.30	0.24	0.28	0.21	0.01	0.01	0.19	0.01	0.01
Tstd_20190510_1150_31	46000	6000	0.08	0.15	0.30	0.22	0.78	344.84	0.26	0.83	0.81	0.42	0.01	0.01	0.97	0.01	0.01
Tstd_20190510_1151_43	46000	6000	0.05	0.25	0.22	0.22	0.68	87.65	0.42	0.18	0.20	0.21	0.01	0.01	0.12	0.01	0.01
Tstd_20190510_1156_14	46000	5400	0.04	0.06	0.33	0.44	0.92	633.78	0.31	0.31	0.27	0.22	0.01	0.01	0.26	0.01	0.01
Tstd_20190510_1156_42	46000	5400	0.07	0.08	0.32	0.29	0.92	665.74	0.24	0.17	0.18	0.16	0.01	0.01	0.16	0.01	0.01
Tstd_20190510_1200_09	46000	4800	0.31	0.05	0.22	0.22	0.80	126.73	0.40	0.56	0.56	0.34	0.01	0.01	0.38	0.01	0.01
Tstd_20190510_1201_39	46000	4200	0.14	0.03	0.33	0.16	0.81	363.68	0.57	0.43	0.50	0.32	0.01	0.01	0.37	0.01	0.01
Tstd_20190510_1202_43	46000	3600	0.23	0.10	0.47	0.47	1.44	0.01	0.28	0.23	0.24	0.16	0.01	0.01	0.22	0.01	0.01
Tstd_20190510_1203_59	51000	3600	0.26	0.22	0.21	0.35	1.27	17.42	0.43	1.03	1.02	0.76	0.01	0.01	1.07	0.01	0.01
Tstd_20190510_1205_24	51000	4200	0.10	0.27	0.27	0.55	1.20	70.26	0.58	0.37	0.26	0.26	0.01	0.01	0.30	0.01	0.01
Tstd_20190510_1206_14	51000	4800	0.20	0.24	0.25	0.20	0.69	32.19	0.49	0.24	0.31	0.30	0.01	0.01	0.42	0.01	0.01
Tstd_20190510_1206_39	51000	4800	0.17	0.14	0.29	0.28	0.74	15.95	0.67	0.94	0.89	0.42	0.01	0.01	0.88	0.01	0.01
Tstd_20190510_1207_23	51000	5400	0.16	0.29	0.38	0.46	0.75	41.93	0.56	0.33	0.36	0.32	0.01	0.01	0.33	0.01	0.01
Tstd_20190510_1210_16	idle	idle	0.22	0.19	0.36	0.41	0.88	226.46	0.31	0.40	0.47	0.22	0.01	0.01	0.32	0.01	0.01

C. 20190531: HEAT EXCHANGER CONFIGURATION WITH COLD SIDE MEASUREMENTS

Atmospheric Pressure:		29.94 inHg																	
Timestamp	N1	ND	1_01	1_02	1_03	1_04	1_05	1_06	1_07	1_08	1_09	1_10	1_11	1_12	1_13	1_14	1_15	1_16	
Pdata_20190531_1047_40	idle	idle	-999999	-244	-11	-13	-12	-12	204	747	112	740	183	687	208	-13	213	-13	
Pdata_20190531_1050_28	51000	3600	-999999	-849	-18	-18	-19	-21	999999	2396	2107	2034	999999	2168	999999	-20	999999	-20	
Pdata_20190531_1052_49	51000	4200	-999999	-847	-18	-18	-19	-19	999999	2399	2146	2090	999999	2137	999999	-21	999999	-20	
Pdata_20190531_1056_10	51000	4800	-999999	-857	-19	-18	-19	-20	999999	2427	2445	2177	999999	2174	999999	-24	999999	-24	
Pdata_20190531_1059_13	51000	5400	-999999	-844	-19	-20	-19	-18	999999	2478	999999	2342	52596	2242	999999	-24	151884	-24	
Pdata_20190531_1101_22	51000	6000	-999999	-844	-21	-18	-19	-19	2654	2614	999999	551218	2528	2366	999999	-24	2223	-24	
Timestamp	N1	ND	1_01	1_02	1_03	1_04	1_05	1_06	1_07	1_08	1_09	1_10	1_11	1_12	1_13	1_14	1_15	1_16	
Pstd_20190531_1046_04	idle	idle	0%	-1.00%	-22.35%	-12.88%	-18.76%	-22.38%	3.19%	0.58%	11.89%	2.41%	1.88%	0.67%	2.03%	-6.22%	15%	-7.56%	
Pstd_20190531_1047_40	idle	idle	0%	-0.81%	-22.53%	-10.60%	-16.03%	-17.73%	1.85%	0.55%	9.50%	2.21%	1.94%	0.70%	1.67%	-6.58%	19.17%	-8.20%	
Pstd_20190531_1050_28	51000	3600	0%	-0.43%	-43.20%	-41.04%	-27.43%	-35.61%	0%	0.93%	6.88%	3.27%	0%	1.04%	0%	-13.54%	0%	-13.64%	
Pstd_20190531_1052_49	51000	4200	0%	-0.51%	-22.57%	-25.34%	-23.70%	-27.98%	0%	1.01%	4.50%	2.09%	0%	0.91%	0%	-12.23%	0%	-12.19%	
Pstd_20190531_1056_10	51000	4800	0%	-0.45%	-25.07%	-38.97%	-26.50%	-26.70%	0%	0.74%	5.90%	2.17%	0%	0.74%	0%	-10.36%	0%	-10.95%	
Pstd_20190531_1059_13	51000	5400	0%	-0.48%	-38.84%	-33.77%	-28.61%	-22.53%	0%	0.93%	0%	2.50%	424%	0.92%	0%	-16.21%	240.70%	-13.25%	
Pstd_20190531_1101_22	51000	6000	0%	-0.38%	-25.85%	-28.82%	-26.84%	-27.81%	1.01%	0.93%	0%	92.35%	0.70%	0.92%	0%	-14.39%	11.38%	-11.67%	
Pstd_20190531_1103_49	idle	idle	0%	-1.19%	-17.86%	-14.45%	-15.11%	-16.68%	2.79%	0.75%	11.06%	2.54%	2.00%	0.77%	2.07%	-4.99%	0%	-4.63%	

Timestamp	N1	ND	2_01	2_02	2_03	2_04	2_05	2_06	2_07	2_08	2_09	2_10	2_11	2_12	2_13	2_14	2_15	2_16
Pdata_20190531_1047_40	idle	idle	-3407	-241	-13	-11	-13	-12	205	749	112	744	183	687	209	-11	214	-12
Pdata_20190531_1050_28	51000	3600	-12893	-846	-17	-20	-22	-18	2869	2398	2112	2035	3116	2167	3545	-18	3623	-19
Pdata_20190531_1052_49	51000	4200	-12292	-845	-16	-17	-16	-17	3040	2401	2153	2092	3074	2136	3503	-18	4413	-19
Pdata_20190531_1056_10	51000	4800	-11806	-853	-16	-18	-19	-17	3056	2430	2449	2179	3009	2173	3411	-19	3431	-22
Pdata_20190531_1059_13	51000	5400	-11350	-840	-16	-15	-15	-18	2825	2483	3161	2337	2736	2242	3098	-19	2326	-23
Pdata_20190531_1101_22	51000	6000	-11296	-841	-16	-16	-18	-19	2658	2619	3411	2759	2529	2365	2873	-20	2224	-23
Timestamp	N1	ND	2_01	2_02	2_03	2_04	2_05	2_06	2_07	2_08	2_09	2_10	2_11	2_12	2_13	2_14	2_15	2_16
Pstd_20190531_1046_04	idle	idle	-0.24%	-0.92%	-15.87%	-14.04%	-13.91%	-15.25%	3.16%	0.55%	11.66%	2.79%	1.78%	0.69%	2.04%	-12.60%	15.06%	-10.15%
Pstd_20190531_1047_40	idle	idle	-0.15%	-0.79%	-19.94%	-15.62%	-18.96%	-14.67%	1.84%	0.62%	9.40%	1.72%	2.05%	0.68%	1.75%	-11.21%	19.26%	-9.92%
Pstd_20190531_1050_28	51000	3600	-0.29%	-0.45%	-44.60%	-30.77%	-35.95%	-26.70%	1.57%	0.94%	6.31%	2.97%	0.88%	1.00%	0.98%	-16.86%	2.37%	-14.23%
Pstd_20190531_1052_49	51000	4200	-0.40%	-0.56%	-17.92%	-28.03%	-24.50%	-20.27%	1.01%	1.01%	4.83%	2.63%	0.96%	0.91%	0.93%	-16.96%	9.24%	-14.90%
Pstd_20190531_1056_10	51000	4800	-0.31%	-0.45%	-26.95%	-24.12%	-24.56%	-28.99%	0.76%	0.75%	5.86%	2.43%	0.56%	0.73%	0.47%	-12.82%	2.33%	-10.93%
Pstd_20190531_1059_13	51000	5400	-0.31%	-0.52%	-38.68%	-44.09%	-39.98%	-40.48%	0.92%	0.93%	5.07%	2.32%	0.58%	0.94%	0.70%	-19.91%	18.76%	-16.24%
Pstd_20190531_1101_22	51000	6000	-0.19%	-0.32%	-25.15%	-25.75%	-27.31%	-24%	0.98%	0.93%	2.02%	2.72%	0.69%	0.91%	0.81%	-17.13%	11.37%	-13%
Pstd_20190531_1103_49	idle	idle	-0.56%	-1.19%	-19.51%	-13.02%	-16.94%	-11.19%	2.98%	0.72%	10.05%	2.41%	2.13%	0.82%	2.06%	-7.56%	-18.30%	-5.67%

Timestamp	N1	ND	3_01	3_02	3_03	3_04	3_05	3_06	3_07	3_08	3_09	3_10	3_11	3_12	3_13	3_14	3_15	3_16
Pdata_20190531_1047_40	idle	idle	-3433	-284	159196	154790	88186	57543	176	729	129	713	137	630	191	-70	192	-42
Pdata_20190531_1050_28	51000	3600	-12928	-883	573178	559922	93886	61635	2838	2390	2126	1990	3080	2098	3480	-104	3572	-78
Pdata_20190531_1052_49	51000	4200	-12318	-889	572018	558768	91949	67665	3015	2366	2163	2071	3071	2095	3442	-74	4388	-78
Pdata_20190531_1056_10	51000	4800	-11843	-887	574637	561188	101317	69046	3045	2424	2484	2145	2997	2132	3340	-80	3404	-87
Pdata_20190531_1059_13	51000	5400	-11377	-864	567259	554116	105365	71353	2812	2485	3193	2294	2716	2204	3017	-93	2330	-72
Pdata_20190531_1101_22	51000	6000	-11325	-874	568349	555382	104867	71981	2640	2607	3409	2724	2504	2327	2794	-95	2225	-68
Timestamp	N1	ND	3_01	3_02	3_03	3_04	3_05	3_06	3_07	3_08	3_09	3_10	3_11	3_12	3_13	3_14	3_15	3_16
Pstd_20190531_1046_04	idle	idle	-0.53%	-6.84%	0.09%	0.12%	0.03%	-67.17%	9.15%	2.07%	16.09%	4.45%	14.66%	3.33%	17.04%	-29.66%	22.01%	-21.30%
Pstd_20190531_1047_40	idle	idle	-0.40%	-6.44%	0.08%	0.09%	0.03%	0.20%	10.93%	2.31%	17.53%	2.86%	14.66%	2.14%	13.82%	-19.80%	20.18%	-27.98%
Pstd_20190531_1050_28	51000	3600	-0.28%	-2.07%	0.20%	0.20%	0.32%	0.74%	1.72%	1.18%	6.51%	3.26%	0.85%	1.12%	1.08%	-16.16%	2.52%	-19.22%
Pstd_20190531_1052_49	51000	4200	-0.38%	-2.14%	0.52%	0.53%	0.41%	0.86%	1.03%	1.22%	4.98%	2.65%	1.05%	1.20%	1.22%	-11.47%	9.31%	-10.91%
Pstd_20190531_1056_10	51000	4800	-0.35%	-2.28%	0.20%	0.20%	0.28%	0.74%	0.76%	0.94%	5.55%	2.56%	0.79%	0.88%	0.79%	-14.66%	2.31%	-20.44%
Pstd_20190531_1059_13	51000	5400	-0.41%	-1.85%	0.14%	0.17%	0.37%	0.50%	1.19%	1.13%	4.84%	2.22%	0.71%	1.21%	0.79%	-20.83%	18.66%	-16.20%
Pstd_20190531_1101_22	51000	6000	-0.23%	-2.27%	0.15%	0.19%	0.26%	0.46%	1.18%	1.08%	1.96%	2.98%	0.95%	1.28%	0.87%	-20.52%	11.20%	-22.80%
Pstd_20190531_1103_49	idle	idle	-0.72%	-6.04%	0.40%	0.39%	0.06%	-21.30%	10.52%	1.25%	20.01%	3.12%	17.03%	2.82%	7.50%	-33.72%	-18.37%	-64.80%

Timestamp	N1	ND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tdata_20190531_1047_40	idle	idle	290.50	290.88	406.12	405.82	805.43	751.99	754.63	740.56	748.21	739.92	2567.15	2567.15	735.65	726.52	690.08
Tdata_20190531_1050_28	51000	3600	300.38	298.77	584.24	581.74	1038.19	872.89	877.53	893.40	898.17	881.11	2567.20	2567.20	892.44	899.46	855.14
Tdata_20190531_1052_49	51000	4200	301.42	300.08	584.95	582.54	1034.71	867.70	876.75	886.27	885.59	870.53	2567.25	2567.25	881.96	2567.25	846.19
Tdata_20190531_1056_10	51000	4800	303.44	301.06	588.09	585.69	1047.77	878.37	883.44	891.98	887.88	871.97	2567.31	2567.31	889.44	2567.31	853.65
Tdata_20190531_1059_13	51000	5400	304.52	302.71	588.18	585.81	1053.86	881.44	881.88	894.85	891.39	868.55	2567.37	2567.37	895.35	2567.37	860.34
Tdata_20190531_1101_22	51000	6000	303.76	302.14	587.86	585.85	1058.68	881.47	879.00	894.74	891.69	865.22	2567.42	2567.42	895.83	2567.42	865.42
Timestamp	N1	ND	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Tdata_20190531_1047_40	idle	idle	292.52	292.70	292.50	292.58	537.15	584.48	548.85	597.61	2567.98	2568.06	2568.06	2568.06	2568.06	2568.06	2568.06
Tdata_20190531_1050_28	51000	3600	293.93	294.01	293.86	293.89	651.61	684.01	653.53	718.25	2568.06	2568.14	2568.14	2568.14	2568.14	2568.14	2568.14
Tdata_20190531_1052_49	51000	4200	295.76	295.80	295.39	295.57	682.74	699.53	641.98	2568.11	2568.11	2568.19	2568.19	2568.19	2568.19	2568.19	2568.19
Tdata_20190531_1056_10	51000	4800	297.88	297.89	297.35	297.33	682.44	712.47	668.76	2568.19	2568.19	2568.28	2568.28	2568.28	2568.28	2568.28	2568.28
Tdata_20190531_1059_13	51000	5400	299.73	299.72	299.06	298.94	696.49	724.70	684.20	2568.27	2568.27	2568.35	2568.35	2568.35	2568.35	2568.35	2568.35
Tdata_20190531_1101_22	51000	6000	300.68	300.66	300.05	299.95	698.18	724.20	689.31	2560.45	2568.32	2568.41	2568.41	2568.41	2568.41	2568.41	2568.41
Timestamp	N1	ND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tstd_20190531_1047_40	idle	idle	0.02%	0.02%	0.01%	0.02%	0.12%	0.03%	0.03%	0.05%	0.05%	0.03%	0.00%	0.00%	0.04%	0.02%	0.15%
Tstd_20190531_1050_28	51000	3600	0.11%	0.11%	0.07%	0.06%	0.09%	0.09%	0.08%	0.04%	0.04%	0.07%	0.00%	0.00%	0.04%	3.82%	0.04%
Tstd_20190531_1052_49	51000	4200	0.09%	0.05%	0.08%	0.09%	0.13%	0.06%	0.06%	0.05%	0.05%	0.05%	0.00%	0.00%	0.06%	0.00%	0.04%
Tstd_20190531_1056_10	51000	4800	0.10%	0.06%	0.04%	0.05%	0.07%	0.07%	0.09%	0.05%	0.05%	0.04%	0.00%	0.00%	0.06%	0.00%	0.02%
Tstd_20190531_1059_13	51000	5400	0.04%	0.04%	0.04%	0.05%	0.07%	0.08%	0.09%	0.07%	0.06%	0.08%	0.00%	0.00%	0.07%	0.00%	0.02%
Tstd_20190531_1101_22	51000	6000	0.05%	0.08%	0.05%	0.05%	0.10%	0.03%	0.04%	0.07%	0.07%	0.03%	0.00%	0.00%	0.06%	0.00%	0.04%
Timestamp	N1	ND	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Tstd_20190531_1047_40	idle	idle	0.02%	0.02%	0.02%	0.03%	1.00%	0.54%	0.95%	0.96%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190531_1050_28	51000	3600	0.05%	0.05%	0.04%	0.05%	1.05%	0.82%	0.80%	0.91%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190531_1052_49	51000	4200	0.04%	0.04%	0.03%	0.04%	0.75%	0.60%	0.52%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190531_1056_10	51000	4800	0.03%	0.03%	0.04%	0.04%	0.39%	0.46%	0.51%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190531_1059_13	51000	5400	0.01%	0.02%	0.03%	0.03%	0.34%	0.34%	0.53%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190531_1101_22	51000	6000	0.00%	0.01%	0.02%	0.02%	0.38%	0.25%	0.34%	1.37%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Timestamp	N1	ND	1	2	3	4
Vdata_20190531_1029_51	_____	_____	0.0166	0.0222	3.1299	0.0155
Vdata_20190531_1046_04	idle	idle	0.0256	0.0335	3.1273	0.024
Vdata_20190531_1047_40	idle	idle	0.4593	0.4848	3.1258	0.3606
Vdata_20190531_1050_28	51000	3600	0.4938	0.4161	3.1235	0.3724
Vdata_20190531_1052_49	51000	4200	0.5288	0.429	3.1199	0.4496
Vdata_20190531_1056_10	51000	4800	0.467	0.4455	3.106	0.3742
Vdata_20190531_1059_13	51000	5400	0.4446	0.4694	3.0921	0.3302
Vdata_20190531_1101_22	51000	6000	0.4572	0.4462	3.0795	0.3418
Vdata_20190531_1103_49	idle	idle	0.0269	0.0343	3.3973	0.0201
Timestamp	N1	ND	1	2	3	4
Vstd_20190531_1029_51	_____	_____	34.76%	21.11%	0.15%	32.31%
Vstd_20190531_1046_04	idle	idle	22.87%	12.68%	0.14%	21.19%
Vstd_20190531_1047_40	idle	idle	0.88%	1.35%	0.16%	1.64%
Vstd_20190531_1050_28	51000	3600	1.34%	1.18%	0.15%	2.62%
Vstd_20190531_1052_49	51000	4200	0.97%	2.89%	0.13%	1.83%
Vstd_20190531_1056_10	51000	4800	1.10%	1.93%	0.13%	2.14%
Vstd_20190531_1059_13	51000	5400	1.40%	1.19%	0.12%	1.36%
Vstd_20190531_1101_22	51000	6000	1.47%	1.88%	0.11%	1.85%
Vstd_20190531_1103_49	idle	idle	18.54%	14.11%	6.87%	36.05%

D. 20190605: HEAT EXCHANGER CONFIGURATION WITH COLD SIDE MEASUREMENTS

Atmospheric Pressure: 29.905 inHg																		
Timestamp	N1	ND	1_01	1_02	1_03	1_04	1_05	1_06	1_07	1_08	1_09	1_10	1_11	1_12	1_13	1_14	1_15	1_16
Pdata_20190605_0926_60	idle	idle	-999999	-237.84	-11.94	-12.01	-12.68	-12.32	196.5	720.55	110.97	722.81	177.33	662.69	201.87	-13.98	194.54	-13.47
Pdata_20190605_0933_12	51000	3600	-999999	-849.47	-17.97	-20.31	-18.43	-19.28	950135.5	2407.58	2119.5	2024.09	999999	2171.25	999999	-19.8	999999	-19.3
Pdata_20190605_0939_21	51000	4200	-999999	-843.37	-17.37	-16.62	-16.66	-16.21	999999	2335.95	2033.31	2074.92	999999	2077.27	999999	-21.14	999999	-20.39
Pdata_20190605_0941_12	51000	4800	-999999	-855.87	-18.22	-19.38	-16.27	-18.05	999999	2403.55	2432.71	2167.36	999999	2148.39	999999	-21.94	999999	-22.18
Pdata_20190605_0943_01	51000	5400	-999999	-844.65	-17.34	-18.13	-18.44	-19.5	950135.68	2471.84	999999	2367.54	52574.57	2231.96	999999	-21.73	999999	-20.9
Pdata_20190605_0944_53	51000	6000	-999999	-845.85	-17.98	-20.19	-17.5	-18.99	2622.51	2595.18	999999	351748.74	2499.41	2355.89	999999	-23.85	501370.94	-23.08
Timestamp	N1	ND	1_01	1_02	1_03	1_04	1_05	1_06	1_07	1_08	1_09	1_10	1_11	1_12	1_13	1_14	1_15	1_16
Pstd_20190605_0926_60	idle	idle	0%	-1.02%	-26.25%	-24.76%	-20.54%	-24.78%	2.49%	0.65%	10.66%	2.66%	1.74%	0.84%	1.71%	-7.37%	10.28%	-7.14%
Pstd_20190605_0933_12	51000	3600	0%	-0.35%	-37.08%	-35.79%	-26.40%	-35.05%	23.47%	1.46%	5.63%	3.89%	0%	1.75%	0%	-12.02%	0%	-11.73%
Pstd_20190605_0939_21	51000	4200	0%	-0.49%	-26.19%	-25.72%	-27.61%	-36.41%	0%	0.56%	5.69%	2.09%	0%	0.69%	0%	-15.78%	0%	-13.77%
Pstd_20190605_0941_12	51000	4800	0%	-0.43%	-32.92%	-31.44%	-25.40%	-21.78%	0%	0.60%	5.78%	2.12%	0%	0.66%	0%	-24.18%	0%	-15.90%
Pstd_20190605_0943_01	51000	5400	0%	-0.28%	-29.16%	-38.94%	-40.49%	-41.30%	23.47%	1.01%	0%	3.22%	424.20%	0.84%	0%	-19.13%	0%	-16.93%
Pstd_20190605_0944_53	51000	6000	0%	-0.33%	-38.21%	-25.88%	-25.44%	-26.25%	0.90%	1.04%	0%	138.70%	0.72%	1.11%	0%	-10.87%	102%	-11.32%

Timestamp	N1	ND	2_01	2_02	2_03	2_04	2_05	2_06	2_07	2_08	2_09	2_10	2_11	2_12	2_13	2_14	2_15	2_16
Pdata_20190605_0926_60	idle	idle	-3271.02	-235.84	-9.24	-11.92	-11.31	-10.17	197.2	724.34	112.51	723.81	177.06	660.89	202.11	-12.32	195.32	-11.81
Pdata_20190605_0933_12	51000	3600	-12580.59	-847.32	-15.15	-20.85	-16.08	-16.25	2829.29	2410.09	2125	2019.44	3099.01	2167.45	3529.28	-19.2	3577.01	-17.86
Pdata_20190605_0939_21	51000	4200	-11490.04	-841.83	-13.76	-18.02	-16.16	-15.86	2968.58	2337.64	2038.62	2072.69	2987.44	2075.14	3398.64	-20.38	3622.04	-18.35
Pdata_20190605_0941_12	51000	4800	-11561.04	-854.68	-15.63	-19.66	-17.07	-19.17	3001.45	2404.64	2455.65	2174.66	2956.24	2146.65	3352.88	-21.15	5636.82	-20.21
Pdata_20190605_0943_01	51000	5400	-11324.89	-844.71	-15.71	-18.54	-17.39	-17.63	2803.58	2473.38	3186.69	2366.81	2711.57	2229.24	3075.16	-21.07	2985.74	-19.08
Pdata_20190605_0944_53	51000	6000	-11292.05	-846.37	-16.36	-20.77	-17.4	-17.79	2622.94	2596.52	3367.92	2735.14	2497.88	2352.58	2842.25	-23.62	2758	-20.86
Timestamp	N1	ND	2_01	2_02	2_03	2_04	2_05	2_06	2_07	2_08	2_09	2_10	2_11	2_12	2_13	2_14	2_15	2_16
Pstd_20190605_0926_60	idle	idle	-0.44%	-0.96%	-25.19%	-19.77%	-19.88%	-19.64%	2.53%	0.68%	10.28%	2.35%	1.83%	0.85%	1.68%	-12%	10.27%	-11.22%
Pstd_20190605_0933_12	51000	3600	-0.34%	-0.33%	-39.90%	-27.96%	-39.31%	-37.59%	1.97%	1.46%	4.77%	3.91%	1.06%	1.71%	1.59%	-14.10%	2.27%	-13.52%
Pstd_20190605_0939_21	51000	4200	-0.28%	-0.47%	-35.09%	-28.17%	-32.41%	-33.20%	0.92%	0.54%	5.43%	2.35%	0.51%	0.69%	0.56%	-18.72%	11.62%	-15.22%
Pstd_20190605_0941_12	51000	4800	-0.21%	-0.38%	-29.75%	-18.51%	-28.72%	-32.18%	0.77%	0.59%	5.35%	2.15%	0.75%	0.68%	0.58%	-25.06%	14.42%	-16.78%
Pstd_20190605_0943_01	51000	5400	-0.12%	-0.29%	-44.26%	-32.92%	-46.81%	-44.04%	1.23%	1.02%	2.85%	3.13%	0.67%	0.84%	0.59%	-20%	0.61%	-22.75%
Pstd_20190605_0944_53	51000	6000	-0.25%	-0.35%	-38.40%	-20.99%	-29.88%	-29.52%	0.93%	1.05%	2.38%	2.47%	0.75%	1.09%	0.70%	-10.67%	0.79%	-12.44%

Timestamp	N1	ND	3_01	3_02	3_03	3_04	3_05	3_06	3_07	3_08	3_09	3_10	3_11	3_12	3_13	3_14	3_15	3_16
Pdata_20190605_0926_60	idle	idle	-3251.74	-189.71	154567.56	150035.45	41572.89	-35.91	200.31	690.01	121.32	679.94	160.54	672.95	199.25	-12.32	212.56	-4.73
Pdata_20190605_0933_12	51000	3600	-12553.33	-780.24	570727.21	557861.88	251323.05	247557.8	2816.36	2419.33	2128.3	1986.29	3087.95	2173.71	3502.28	-45.51	3605.58	-53.04
Pdata_20190605_0939_21	51000	4200	-11496.8	-780.24	561905.61	549298.33	242969.81	401.98	2967.79	2324.65	2031.97	2010.35	2978.26	2080.05	3373.43	-60.68	3648.23	-51.15
Pdata_20190605_0941_12	51000	4800	-11578.06	-803.58	568739.42	555668.43	243592.37	-355.22	3006.12	2389	2453.77	2104.83	2935.17	2146.13	3314.78	-70.16	5666.38	-49.25
Pdata_20190605_0943_01	51000	5400	-11344.86	-788.02	564355.32	551448.12	244350.3	-29.08	2787.55	2459.03	3170.24	2273.43	2690.4	2234.25	3052.01	-34.13	3034.99	-41.68
Pdata_20190605_0944_53	51000	6000	-11311.61	-795.8	564818.63	551793.46	244307.64	-50.42	2599.65	2570.71	3328.16	2671.78	2471.09	2351.73	2838.66	-28.44	2800.17	-32.2
Timestamp	N1	ND	3_01	3_02	3_03	3_04	3_05	3_06	3_07	3_08	3_09	3_10	3_11	3_12	3_13	3_14	3_15	3_16
Pstd_20190605_0926_60	idle	idle	-0.77%	-11.55%	0.35%	0.36%	3.60%	-37.82%	14.03%	2.63%	18.39%	5.01%	13.30%	3.97%	16.12%	-176.20%	13.07%	-412.90%
Pstd_20190605_0933_12	51000	3600	-0.34%	-1.12%	0.28%	0.31%	0.26%	0.30%	1.95%	1.43%	5.38%	3.80%	1.11%	1.95%	1.63%	-34.20%	2.26%	-35.90%
Pstd_20190605_0939_21	51000	4200	-0.32%	-1.12%	0.19%	0.19%	0.11%	180.40%	1.06%	0.97%	5.60%	2.46%	0.80%	0.86%	0.88%	-31.41%	11.37%	-36.25%
Pstd_20190605_0941_12	51000	4800	-0.24%	-2.37%	0.17%	0.17%	0.13%	-81.11%	0.96%	1.02%	4.84%	2.11%	1.01%	0.87%	0.67%	-26.45%	14.46%	-36.17%
Pstd_20190605_0943_01	51000	5400	-0.20%	-2.19%	0.11%	0.15%	0.08%	-879.20%	1.42%	1.06%	3.11%	3.75%	0.83%	0.96%	0.63%	-61.39%	0.89%	-27.98%
Pstd_20190605_0944_53	51000	6000	-0.27%	-2.50%	0.17%	0.19%	0.13%	-735.20%	1.48%	1.06%	1.82%	3.39%	1.14%	1.48%	1.14%	-73.35%	0.81%	-69.08%

Timestamp	N1	ND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tdata_20190605_0926_60	idle	idle	293.73	294.17	408.07	408.36	797.80	744.82	747.28	736.61	744.25	732.30	2566.76	2566.76	731.29	2566.76	699.59
Tdata_20190605_0933_12	51000	3600	300.53	300.47	584.31	583.27	1039.40	875.93	878.93	894.12	898.48	882.86	2566.94	2566.94	892.55	2566.94	857.17
Tdata_20190605_0939_21	51000	4200	304.91	302.88	587.14	584.43	1033.94	869.86	878.46	887.89	886.49	871.50	2566.99	2566.99	882.76	2566.99	849.66
Tdata_20190605_0941_12	51000	4800	304.82	302.81	590.23	587.88	1049.47	882.05	886.99	894.12	889.63	875.22	2567.05	2567.05	891.00	2567.05	857.87
Tdata_20190605_0943_01	51000	5400	306.06	303.80	589.65	587.26	1054.41	881.04	881.61	895.60	891.68	868.43	2567.10	2567.10	896.05	2567.10	863.60
Tdata_20190605_0944_53	51000	6000	306.16	304.47	590.79	588.79	1062.33	884.78	882.52	898.75	895.41	868.27	2567.16	2567.16	899.61	2567.16	871.01
Timestamp	N1	ND	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Tdata_20190605_0926_60	idle	idle	298.11	298.15	298.11	298.24	373.61	377.18	382.68	378.20	2567.62	2567.71	2567.71	2567.71	2567.71	2567.71	2567.71
Tdata_20190605_0933_12	51000	3600	298.66	299.00	298.92	299.27	644.45	476.12	475.21	464.43	2567.81	2567.90	2567.90	2567.90	2567.90	2567.90	2567.90
Tdata_20190605_0939_21	51000	4200	301.17	301.48	301.52	301.95	511.94	523.14	539.11	518.85	2567.95	2568.05	2568.05	2568.05	2568.05	2568.05	2568.05
Tdata_20190605_0941_12	51000	4800	301.84	302.14	302.17	302.64	525.55	533.46	571.17	530.52	2568.00	2568.09	2568.09	2568.09	2568.09	2568.09	2568.09
Tdata_20190605_0943_01	51000	5400	302.57	302.83	302.87	303.34	530.90	544.89	567.62	543.60	2568.04	2568.14	2568.14	2568.14	2568.14	2568.14	2568.14
Tdata_20190605_0944_53	51000	6000	303.33	303.59	303.62	304.09	536.21	541.44	535.14	552.92	2568.10	2568.19	2568.19	2568.19	2568.19	2568.19	2568.19

Timestamp	N1	ND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tstd_20190605_0926_60	idle	idle	0.04%	0.03%	0.06%	0.07%	0.11%	0.03%	0.03%	0.02%	0.02%	0.03%	0.00%	0.00%	0.02%	0.00%	0.01%
Tstd_20190605_0933_12	51000	3600	0.24%	0.05%	0.12%	0.07%	0.13%	0.07%	0.07%	0.09%	0.11%	0.03%	0.00%	0.00%	0.09%	0.00%	0.03%
Tstd_20190605_0939_21	51000	4200	0.09%	0.05%	0.07%	0.06%	0.08%	0.09%	0.08%	0.05%	0.06%	0.07%	0.00%	0.00%	0.04%	0.00%	0.01%
Tstd_20190605_0941_12	51000	4800	0.08%	0.02%	0.05%	0.07%	0.07%	0.10%	0.10%	0.10%	0.11%	0.08%	0.00%	0.00%	0.09%	0.00%	0.03%
Tstd_20190605_0943_01	51000	5400	0.05%	0.04%	0.04%	0.06%	0.07%	0.09%	0.09%	0.07%	0.08%	0.06%	0.00%	0.00%	0.08%	0.00%	0.03%
Tstd_20190605_0944_53	51000	6000	0.05%	0.05%	0.05%	0.05%	0.10%	0.07%	0.07%	0.05%	0.05%	0.04%	0.00%	0.00%	0.06%	0.00%	0.03%
Timestamp	N1	ND	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Tstd_20190605_0926_60	idle	idle	0.01%	0.01%	0.01%	0.01%	0.22%	0.07%	0.06%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190605_0933_12	51000	3600	0.01%	0.01%	0.01%	0.02%	0.88%	0.92%	0.84%	0.88%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190605_0939_21	51000	4200	0.01%	0.01%	0.01%	0.01%	0.34%	0.42%	0.75%	0.26%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190605_0941_12	51000	4800	0.01%	0.01%	0.01%	0.01%	0.18%	1.13%	1.17%	0.39%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190605_0943_01	51000	5400	0.01%	0.01%	0.01%	0.01%	0.23%	2.64%	1.31%	0.24%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tstd_20190605_0944_53	51000	6000	0.01%	0.01%	0.01%	0.01%	0.16%	1.48%	1.85%	0.49%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Timestamp	N1	ND	1	2	3	4
Vdata_20190605_0859_10	_____	_____	0.0014	0.0165	3.1387	0.0155
Vdata_20190605_0910_16	idle	idle	0.0042	0.0322	3.1323	0.026
Vdata_20190605_0925_00	idle	idle	0.0036	0.0201	3.0982	0.0134
Vdata_20190605_0926_60	idle	idle	0.0041	0.0218	3.0935	0.0156
Vdata_20190605_0933_12	51000	3600	0.0024	0.2545	3.0833	0.2662
Vdata_20190605_0939_21	51000	4200	0.0037	0.2947	3.0679	0.2716
Vdata_20190605_0941_12	51000	4800	0.0022	0.2901	3.3978	0.278
Vdata_20190605_0943_01	51000	5400	0.004	0.2736	3.0573	0.2608
Vdata_20190605_0944_53	51000	6000	0.0047	0.2759	3.0496	0.2505
Vdata_20190605_0949_24	idle	idle	0.0042	0.0335	3.0357	0.0237
Timestamp	N1	ND	1	2	3	4
Vstd_20190605_0859_10	_____	_____	365.90%	36.80%	0.13%	35.72%
Vstd_20190605_0910_16	idle	idle	136.43%	23.12%	0.13%	29.66%
Vstd_20190605_0925_00	idle	idle	148.91%	102.50%	0.15%	44.03%
Vstd_20190605_0926_60	idle	idle	108.04%	32.02%	0.14%	45.03%
Vstd_20190605_0933_12	51000	3600	231.77%	2.81%	0.15%	1.89%
Vstd_20190605_0939_21	51000	4200	138.15%	1.66%	0.10%	1.83%
Vstd_20190605_0941_12	51000	4800	290.04%	2.31%	7.12%	1.34%
Vstd_20190605_0943_01	51000	5400	113.64%	1.60%	0.15%	8.41%
Vstd_20190605_0944_53	51000	6000	109.26%	2.87%	0.13%	2.03%
Vstd_20190605_0949_24	idle	idle	89.35%	22.54%	0.14%	12.97%

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

- [1] Department of Defense, “Fiscal year 2016 operational energy annual report,” Washington, DC, 2016.
- [2] Department of Energy, “Memorandum of understanding between U.S. Department of Energy and U.S. Department of Defense concerning cooperation in a strategic partnership to enhance energy security,” Washington, D.C., 2010.
- [3] “DoD’s Energy Efficiency and Renewable Energy Initiatives,” Environmental and Energy Study Institute, Washington, DC, 2011.
- [4] E. H. Lundquist, “Navy to modernize aging aegis cruisers,” 1 August 2003. [Online]. Available: <http://www.nationaldefensemagazine.org/articles/2003/8/1/2003august-navy-to-modernize-aging-aegis-cruisers>
- [5] S. J. Polsinelli, “Waste Heat Recovery Carbon Dioxide Heat Exchanger for Gas Turbine Engines,” June 2018. [Online]. Available: <https://calhoun.nps.edu/handle/10945/59567>
- [6] C. Buck, “Waste Heat Recovery System For a Gas Turbine Engine and Carbon Dioxide Compression Simulation,” December 2018. [Online]. Available: <https://calhoun.nps.edu/handle/10945/61321>
- [7] T. D. Belna, “Upgrade Transonic Compressor Test Rig Data Acquisition System,” June 2018. [Online]. Available: <https://calhoun.nps.edu/handle/10945/59667>
- [8] C. Xu and M. Muller, “Development and design of a centrifugal compressor volute,” *International Journal of Rotating Machinery*, vol. 2005, no. 3, pp. 190–196, January 2005.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
Ft. Belvoir, Virginia
2. Dudley Knox Library
Naval Postgraduate School
Monterey, California